ENGINEERING DRAWING

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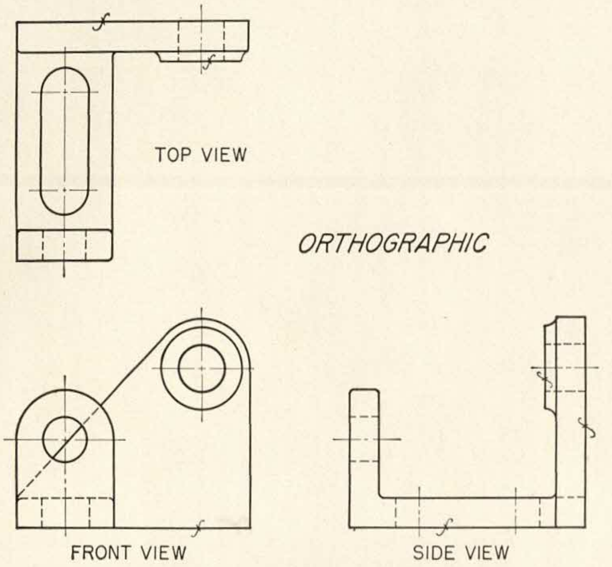
ENGINEERING DRAWING



ENGINEERING

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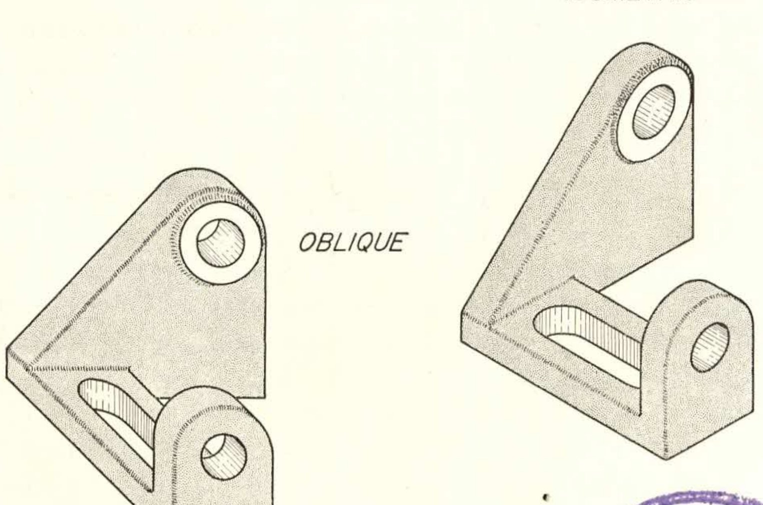

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PREFACE

The second edition of "Engineering Drawing" incorporates many helpful suggestions concerning the contents of the first edition sent in to the author by its many users. The second edition is also a result of the author's desire to place at the disposal of teachers, students, practicing draftsmen, and trained engineers a volume that not only keeps pace with the requirements of industry and technology but makes easily and readily available to them the fundamentals and most desirable concepts of the subject of engineering drawing in a clear, concise, and amply illustrated text. The straightforward and nontechnical language employed is supplemented by hundreds of easy-to-visualize pictorials and step-by-step orthographic-solution drawings, which help explain the freehand or instrument techniques applicable or the graphic procedures required to accomplish desired results or secure precise solutions.

All the chapters for this edition have been revised, some quite extensively. Notably, in addition to other related material, the chapter on dimensioning contains a discussion of surface, geometric-form, and positional tolerancing. The chapter on cams and gears has been completely revised with the aid of Prof. Joseph E. Shigley, University of Michigan, to whom I am also indebted for his contribution of the sections on jigs and fixtures that round out the chapter. One of the new chapters, Descriptive Geometry, explains the solutions for space problems of points, lines, and planes. The coverage given to the subject is simplified and time-saving and should satisfy the ordinarily encountered problem needs of the practicing draftsman and engineer.

My thanks are extended to Prof. Charles J. Baer, University of Kansas, for his unique and much needed treatise in an over-all text of this kind, the new chapter entitled Electrical Drawing. In its broad and comprehensive scope, the student can acquire the essential information to enable him to employ effectively the symbols and drafting procedures used in preparing drawings of this type. Thanks are also due to Prof. Thomas W. Brockenbrough who wrote the new chapter on structural drawing. His decision to limit his discussion to the most important phases of the topic has provided a valuable compact work that permits a thorough grasp of the fundamentals used in detailing and dimensioning structural forms. Credit is due to Prof. John T. Rule, Massachusetts Institute of Technology, on the basis of whose suggestions Jeffrey Norton prepared the new chapter Charts, Graphs, and Nomographs. The beginner should not find it difficult to acquire the rudiments employed for the analyses or solutions of problems in this category.

The problems have been placed at the end of each chapter. They were carefully selected to emphasize the learning points discussed in the text. Ranging from the elementary to the more difficult and complex, their variety and abundance give the discerning teacher a wide choice of problem material. The supplementary information required for the working of those particular problems where further knowledge is needed can be found in the Appendix tables and charts especially selected for this purpose.

A workbook directly keyed to this text is now available. In addition to 85 conventional-type (machine forms, etc.) plates, it contains 50 problems (15 plates) in descriptive geometry and intersections and developments. The material offered in both the text and the workbook conforms to the recommendations of the American Standards Association.

Many individuals have made this second edition possible. It would be out of the question to attempt to list them all or mention their particular contributions. However, I should like particularly to express my appreciation to Profs. John R. Barylski, Thomas A. Wright, and Irwin Wladaver for the generous assistance they have given, with their critical reading and valuable suggestions, in the revising of old material and the adding of new and to Charles H. Dickinson and David M. Robinson, who proofread with me the galley and page proofs.

The author appreciates receiving permission to reproduce certain illustrative material, where due credit also appears.

FRANK ZOZZORA

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CORRELATED ENGINEERING DRAWING FILMS

The following educational motion pictures are especially recommended for use with various chapters of this book as indicated below:

According to Plan—An introduction to engineering drawing. (9 minutes.) For Introduction.

Orthographic Projection—Explains shape description and principles of orthographic projection. (18 minutes.) For Chapter 2.

Drawings and the Shop—Explains relationship between making the drawing and production operations in shop. (15 minutes.) For Chapter 6.

Selection of Dimensions—Explains the principles governing the choice of dimensions and their application. (18 minutes.) For Chapter 7.

Sections and Conventions—Describes the various kinds of sections, and conventional principles and practices. (15 minutes.) For Chapter 8.

Auxiliary Views: Single Auxiliaries—Reviews orthographic projection, and explains auxiliary projection. (23 minutes.) Chapter 9.

Auxiliary Views: Double Auxiliaries—Reviews orthographic projection, and describes theory of double auxiliary. (13 minutes.) For Chapter 10.

Pictorial Sketching—Demonstrates the basic principles of pictorial sketching for the engineer. (11 minutes.) For Chapter 11.

Oblique Cones and Transition Developments—Development of an oblique cone, and transitions. (11 minutes.) For Chapter 16.

Simple Developments—Animated drawings explain what simple developments are and how they are made. (11 minutes.) For Chapter 16.

Each of the above films is 16mm, sound, black and white and may be purchased from Text-Film Department, McGraw-Hill Book Company.

INTRODUCTION

Drawing has often been called the universal language, and engineering drawing is the particular phase of this graphic language that the engineer uses to convey to others his idea of the size, shape, and construction of a part or mechanism. Although the engineer is not always required to make a carefully finished drawing, he must be able to produce an acceptable representation that can be followed accurately, speedily, and with economy of time and effort by those who are to perform the operations or tasks required in making the object shown in the plan. The engineer must understand completely the fundamentals involved, for, in addition to making his own sketches and drawings, he must supervise and counsel others.

You as a technical student should not require strong urging. When you are ready to embark on your career, regardless of the branch of engineering you have chosen to follow, the chances are that you will earn your first money at the drawing board.

This text has been prepared with the following main objectives in mind: (1) To give the practicing engineer the opportunity to review and reassimilate the fundamentals of the subject quickly and readily. (2) To offer the teacher the assurance that in covering the essentials of the subject in the limited time allotted him in his curtailed curriculum he is giving his students the basic knowledge required of them for further development in specialized industry and the profession. (3) To provide the student with the essentials and techniques of engineering drawing without requiring him to learn about highly specialized details of a particular or specific practice that can be more readily acquired on the job.

It has been said that 90 per cent of all learning is acquired through seeing. Accordingly, visual aids in the form of three-dimensional drawings of all types have been employed freely in conjunction with the orthographics wherever it has been felt that pictorial treatment would further aid you in understanding the points set forth. Your careful study of the simple but direct illustrations will relieve your teacher of the need for discussing much that is elementary but time-consuming.

Although brevity is the keynote throughout the text, it has not been gained at the expense of omitting essential material. Instead, whatever might have appeared as repetitive or superfluous has been excluded to avoid confusing the reader.

Because the chapters are complete units in themselves, they may be studied in any desired order or manner. However, long experience has suggested a chapter sequence that should lead to easy progress in the study of the subject. Following the chapter on lettering, you are introduced directly to the basic theory of orthographic projection, which has been carefully pictured and explained. This is followed by a chapter on freehand detail drafting, which permits you to apply the orthographic-projection theory immediately without first having to master the use of instruments. It is hoped that this arrangement will help to establish clearly the aims and principles of engineering drawing at an early stage and to stimulate your interest in drafting techniques and instrument work, including the exercises in geometrical constructions. The chapter on freehand drafting should prove rewarding to the practicing engineer and others who have a desire to improve upon their ability along that line. It should be noted here that most of the drawing a

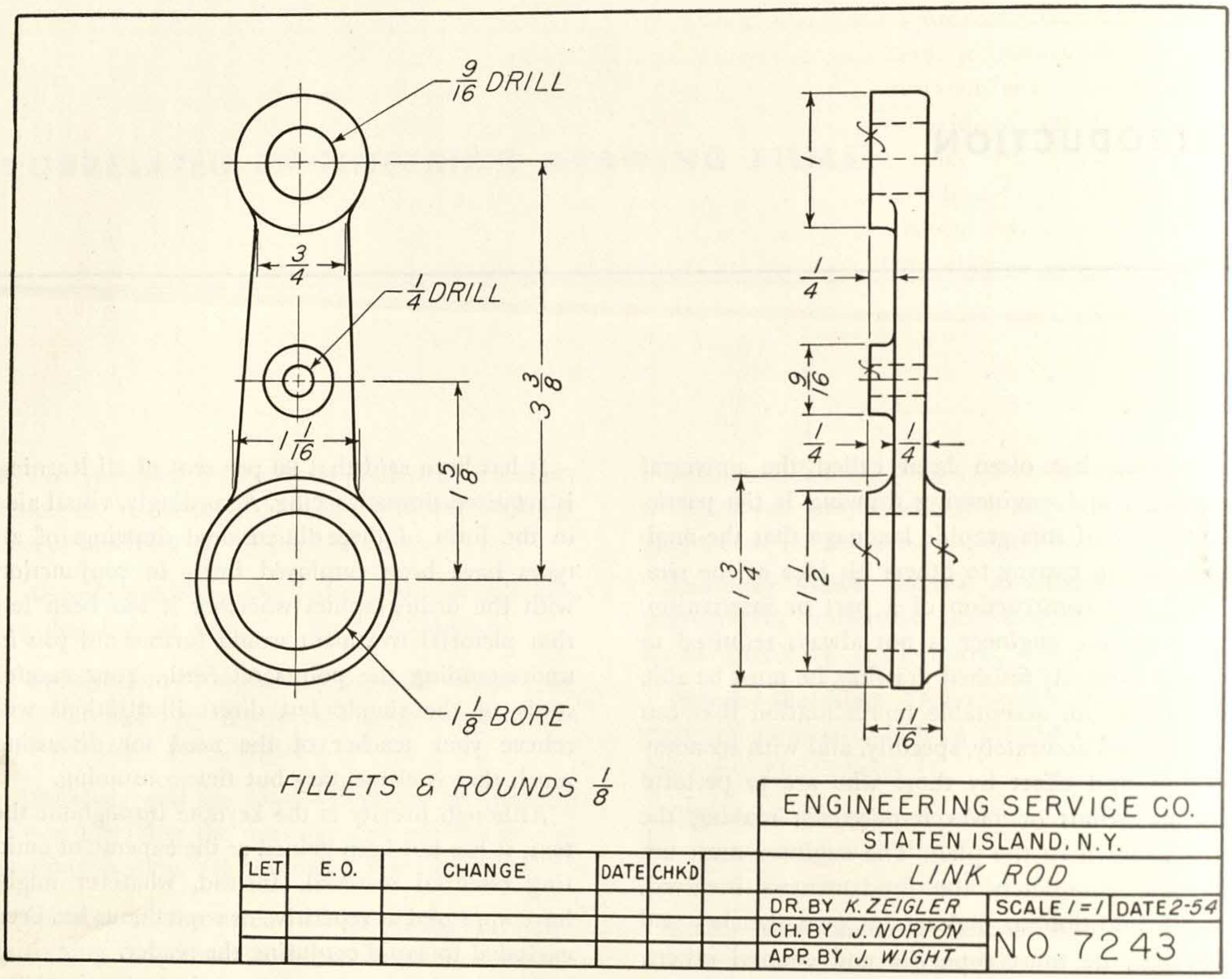


Fig. 1-1. A typical engineering drawing.

busy engineer will do in the future will be freehand sketching; the finished drawings will be executed by his assistants or by the draftsmen in the drafting room.

Whenever applicable, discussions and techniques outlined in this text have been made to conform to the recommendations of the American Standards Association (ASA) . This organization is made up of representatives from the teaching profession and from industry. The Association is constantly working toward the standardization of various practices and procedures in the manufacturing industries and in the engineering profession. Its publications, which are called Standards or Tentative Standards, number more than 100; they are very helpful, not only to the designer, but also to the draftsman. Of the many Standards published, perhaps the most useful to the draftsman is Drawings and Drafting Room Practices. Of almost equal importance, however, are the Standards that have been prepared on more specialized phases of engineering-drawing procedure, such as those on symbols, abbreviations, and layouts and on piping, welding, electrical, and chemical diagrams. A complete list of the Standards may be obtained by communicating with the ASA at its offices in New York.

The Bibliography at the end of this book provides a list of many of the commonly used Standards. Also included in the Bibliography is a list of books on subjects allied to engineering drawing which you should find of assistance when more detail is required than is possible to give in this text.

You can get much valuable information on design, drawing, and dimensioning by referring to the several types of engineers' handbooks and the many manufacturers' catalogues. A collection of catalogues should complement your equipment because many unstandardized but commonly used parts are illustrated in these special publications prepared under the direction of the engineers associated with the manufacturing companies.

A Glossary of the most commonly used shop terms will be found at the end of Chap. 6 and explains the meanings of various specialized terms used in industry and also includes illustrations for ready comprehension.

The Appendix contains tables and design information on commonly used fastening devices, on the classification of fits, and on other detail matters which you will find helpful in working the problems in this text. Also included are a conversion table and a table of trigonometric functions.

The pursuits in which you as a technically trained person may apply your knowledge of engineering drawing are many and diversified. Engineering-drawing ability is a requisite for anyone employed in the engineering field, for it will be found useful in all branches of the profession. The brief descriptions in the following paragraphs, covering the four main branches of engineering, indicate a number of typical ways in which engineering drawing is useful to the practicing engineer.

Civil engineering. The education of the civil engineer is intended to equip him with a knowledge that will enable him to design and construct roads, bridges, railways, subways, tunnels, airports, harbor installations, etc. He is trained in the principles of planning and maintaining transportation facilities, water and power supply, and irrigation and drainage systems. In order to do his work well, he must have a sound knowledge of engineering drawing so as to be able to prepare structural, erection, installation, and plant-layout drawings, as well as maps and route surveys.

Electrical engineering. Electrical engineers may find their interests in several special fields, such as communications, power, or electronics. In each of these fields, the practicing electrical engineer may expect to utilize his knowledge of engineering drawing in the preparation of plans and diagrams for the erection or installation of equipment and apparatus. He must be fully acquainted with the conventional electrical drawing procedures and symbols in order to make wiring and circuit diagrams speedily and efficiently.

Chemical engineering. The chemical engineer's training is intended to enable him to devise and construct equipment for chemical cracking and synthesis and to develop new products for general and industrial use. The chemical engineer should be prepared to make the sketches and finished drawings of flow and process diagrams and the details and assemblies of the mechanisms he designs for his work. He must also prepare diagrammatic, installation, and erection drawings for his workmen to follow.

Mechanical engineering. As a general rule, the mechanical engineer will be primarily interested in the design and development of machines and mechanisms, and he must be familiar with all phases of their operation and proper maintenance. He will apply a knowledge of engineering drawing in the preparation of original sketches and designs, in the construction of graphs and charts expressing engineering calculations and solutions, and in the drawing of detail and assembly plans for the machines and mechanisms that he creates. As a plant engineer he should also be able to construct erection and installation drawings and plant layouts.

A scientifically and technically minded person may also find his lifework in another engineering field, such as industrial, aeronautical, agricultural, and sanitation engineering. These all require many of the basic courses necessary to the training of the civil, electrical, chemical, and mechanical engineer; and, for all, a thorough understanding of the fundamental principles of engineering drawing is an indispensable part of their educational background.

Chapter 1

ENGINEERING LETTERING

In order to construct a part or structure, the workman must have a complete description of its shape and size. The various views on the drawing sheet show the part's contours, but figured dimensions and lettered notes are needed to explain the pictured forms. In keeping with the principle that a good engineering drawing enables the worker to do his job quickly, easily, and economically, the simplest of lettering forms, the single-stroke modern gothic, has been adopted almost universally for all letters and numerals. In addition to perfect legibility, single-stroke gothic letters may be drawn rapidly, which is a significant advantage to the draftsman. The term *single-stroke* means that there is no variation in the width of the lines that make up the letter, and not that the letter is begun and completed in a single movement of the pencil.

To become adept at the art of lettering, the draftsman must:

1. Acquire a thorough knowledge of the proportion and design of each letter and the order and the direction of the strokes used to produce it.
2. Learn to compose letters in the formation of words and to space words properly in sentences.
3. Practice consistently and conscientiously. The beginning draftsman should form the habit of lettering the entire alphabet and a practice sentence each day.

Lettering is a form of freehand drawing, and its attractiveness and legibility enhance the entire graphic presentation on the drawing sheet. The lettering of notes, dimensions, specifications, finishes, and other required information should never be crowded, placed haphazardly, or appear to have been done hurriedly.

Two types of gothic letters are used on engineering drawings—the vertical and the inclined. Both styles are widely used in industry. The vertical letters are more difficult to produce because the slightest variation from verticality is easily detected by the eye. They are becoming increasingly popular in professional practice because of their easy readability. However, the slant letters seem to flow more readily from the pencil.

1-1. Uniformity. The lettering on the drawing sheet should be uniform in appearance. The inclination or verticality, the weight and strength of lines, the height and width of each letter, and the spacing of letters in words and words in sentences are the important considerations in assuring a good appearance (see Fig. 1-1).

1-2. Proportions of letters. Good lettering consists essentially in spacing and arranging the lines and masses of the individual letters so that they will be pleasing to the observer. A thorough study and knowledge of the particular and individual characteristics of each letter and the space it is to occupy in the word structure are of the utmost importance to good lettering.

At times, space considerations may demand that

LETTERING THAT IS VERTICAL, UNIFORM IN HEIGHT, AND MADE WITH THE PROPER WEIGHT OF STROKE LINE, IS BOTH PLEASING AND EFFECTIVE.

Fig. 1-1. Vertical single-stroke modern gothic lettering.

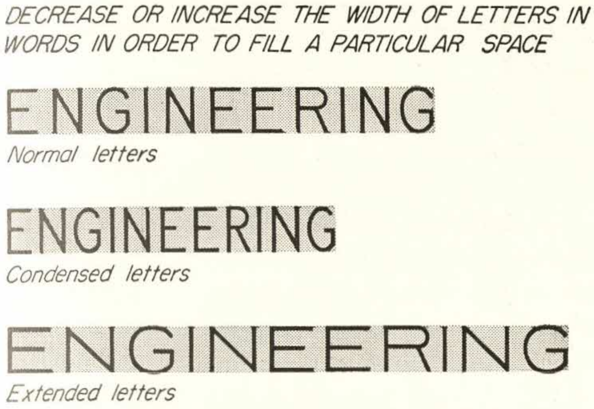

DECREASE OR INCREASE THE WIDTH OF LETTERS IN WORDS IN ORDER TO FILL A PARTICULAR SPACE
ENGINEERING
Normal letters
ENGINEERING
Condensed letters
ENGINEERING
Extended letters

Fig. 1-2. Normal, condensed, and extended letters.

the letters be made either narrower or wider than normal. Such letters are known as *condensed* and *extended* letters, respectively (see Fig. 1-2). In lettering a drawing, the condensed, extended, and normal types of lettering should never be intermixed in the forming of a word or sentence.

1-3. Boldface and lightface letters. Dominance or subordination may be achieved by varying the thickness of the pencil stroke without changing the style or the height of the letters (Fig. 1-3).

1-4. Pencils for guide lines and lettering. Guide lines are indispensable for producing good lettering. The extremely light vertical and horizontal guide lines are drawn with a hard pencil such as a 4H. The letters themselves require a lead of medium-soft grade, but black enough and hard enough to produce a clean, dark line. An HB or 2H

LIGHTFACE

BOLDFACE

Fig. 1-3. Lightface and boldface lettering.

lead that is well pointed and kept so by frequent sharpening will bring satisfactory results.

1-5. Pens for lettering. A complete discussion of the various types of pens that may be used for lettering can be found in Chap. 20, Inking Practice.

1-6. Guide lines. Horizontal guide lines are used to regulate the height of the letters, and vertical or slope guide lines help to keep the angle of the letters uniform (see Fig. 1-4*a*). Horizontal guide lines should be drawn with a T square and vertical guide lines with a T square and triangle (see Fig. 1-4*b*). Vertical guide lines are drawn at random spacing, since they are not intended to space the letters either in words or sentences.

Guide lines should be drawn so lightly that they will not require erasing. Horizontal guide lines, which regulate the height of the letters and the space between lines of lettering, may be located by using the scale as shown in Fig. 1-5, although practice will eventually enable the draftsman to space by eye. The space between guide lines and the height of the letters may be increased or reduced while the proper proportion between the height of the letters and the space between lines is

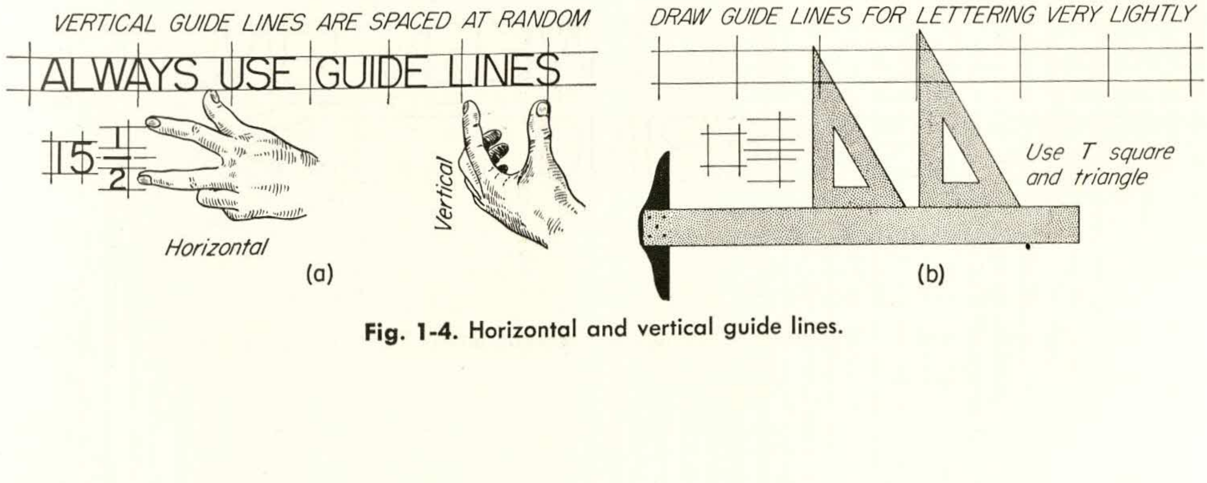
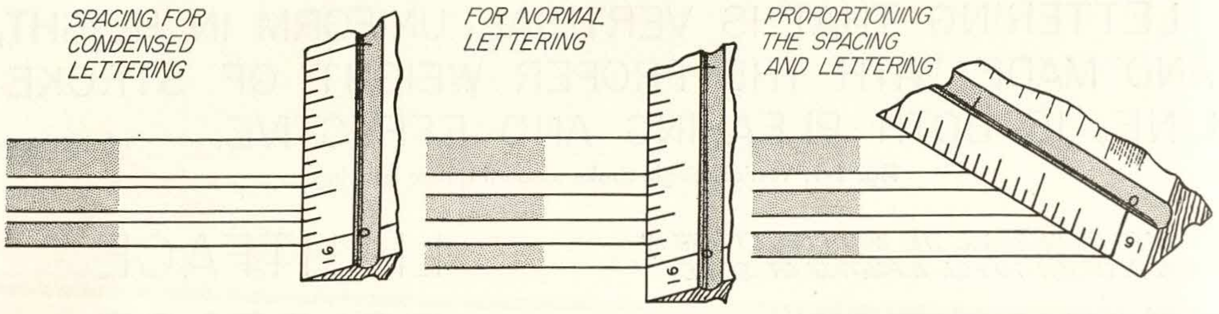

VERTICAL GUIDE LINES ARE SPACED AT RANDOM
ALWAYS USE GUIDE LINES
1 1/2
Horizontal
Vertical
(a)
DRAW GUIDE LINES FOR LETTERING VERY LIGHTLY
Use T square and triangle
(b)

Fig. 1-4. Horizontal and vertical guide lines.


SPACING FOR CONDENSED LETTERING
FOR NORMAL LETTERING
PROPORTIONING THE SPACING AND LETTERING
16
16
16

Use 4H pencil for guide lines

Fig. 1-5. Laying out and spacing guide lines with the scale.

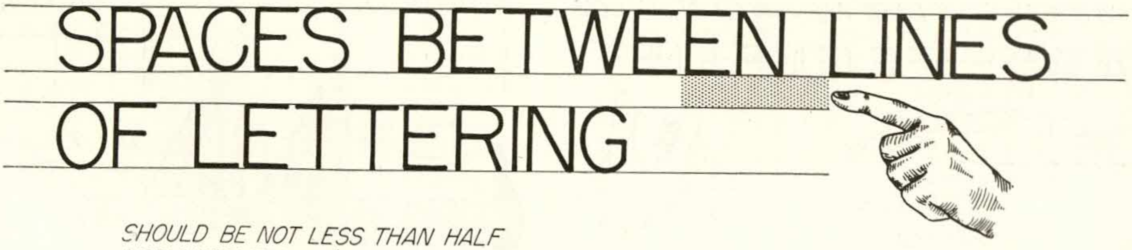
still retained by holding the scale at an angle, as in the right-hand portion of Fig. 1-5.

The lettering for working drawings is commonly $\frac{3}{16}$ in. high for the titles and $\frac{1}{8}$ in. high for the notes, etc., with a space of $\frac{1}{8}$ in. between the lines of lettering. As illustrated in Fig. 1-5, if condensed lettering is used, the space between lines should be less than the height of the letters, say, $\frac{1}{16}$ in. if the letters are $\frac{1}{8}$ in. high, or ranging anywhere between one-half to three-fourths the height of the letter. A safe procedure to follow would be to make the spaces between lines smaller than the height of the letters when compressed lettering is used, equal to the height of the letter when the letters are normal, and greater than the height of the letters when the letters are of the extended type (see Fig. 1-6).

Lettering devices, such as the Braddock-Rowe triangle and the Ames lettering instrument, are often used in drawing and spacing guide lines (see Fig. 1-7). The point of the pencil is inserted into the proper hole, and the guide lines are drawn by moving the instrument along the edge of the T square with the pencil. Various groups of holes on the instruments allow the drawing of a great variety of properly spaced guide lines.

1-7. Lettering strokes. The individual letters of the alphabet are comprised of various strokes. In one or two cases, a single stroke will produce the letter; in all other instances, the letters are made up of straight lines, curved lines, or straight- and curved-line combinations. A knowledge of the direction in which these strokes move and a mastery of the method by which they are produced constitute the essence of the study of lettering.

The vertical stroke of a letter is produced by a finger movement from above downward (Fig. 1-8*a* and *g*). The horizontal stroke starts at the left and moves right with a complete hand movement, as in (*b*) and (*h*). The inclined, or slant, strokes start from above and move downward toward the right (*c*) or left (*d*), whichever is required. These strokes are a combination of finger and hand movements. The curved strokes (Fig. 1-8*e* and *f*) always start from above and move in the desired direction by a combination finger-and-hand movement made possible by resting the hand on the ball of the palm. To form a proper foundation for good lettering, the student must make a serious effort to become familiar with and master the direction and order of each stroke for every letter in the alphabet and for every number.



SHOULD BE NOT LESS THAN HALF
NOR MORE THAN $1\frac{1}{2}$ TIMES THE
HEIGHT OF THE LETTERS

Fig. 1-6. Spaces between lines.

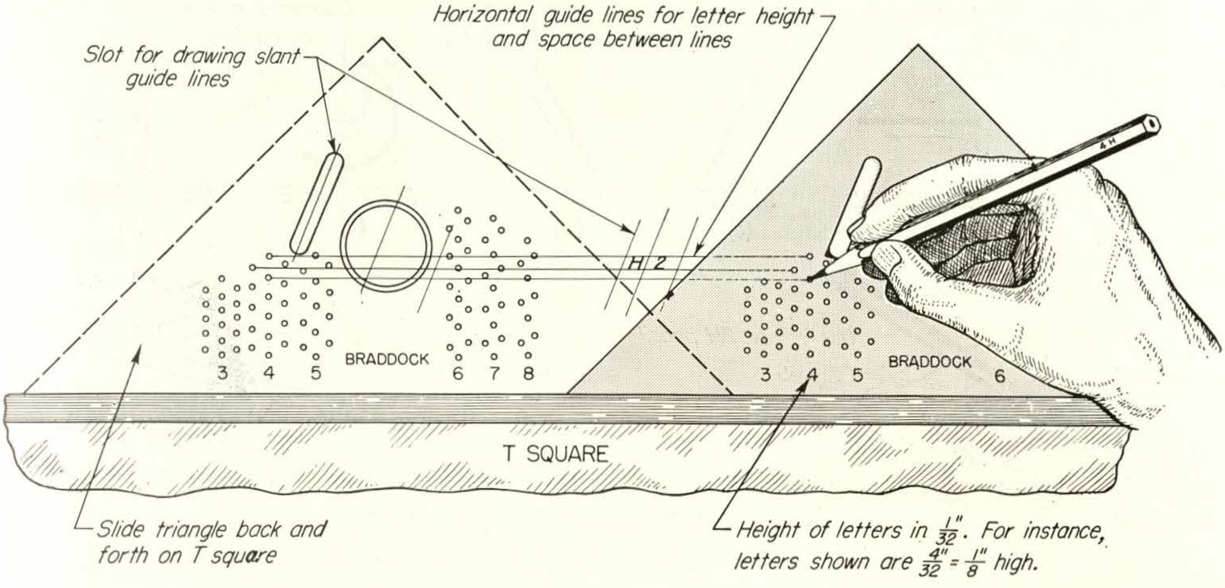

Horizontal guide lines for letter height and space between lines
Slot for drawing slant guide lines
H/2
BRADDOCK
3 4 5 6 7 8
4H
T SQUARE
Slide triangle back and forth on T square
Height of letters in 1/32". For instance, letters shown are 4/32" = 1/8" high.

Fig. 1-7a. Braddock-Rowe lettering triangle.

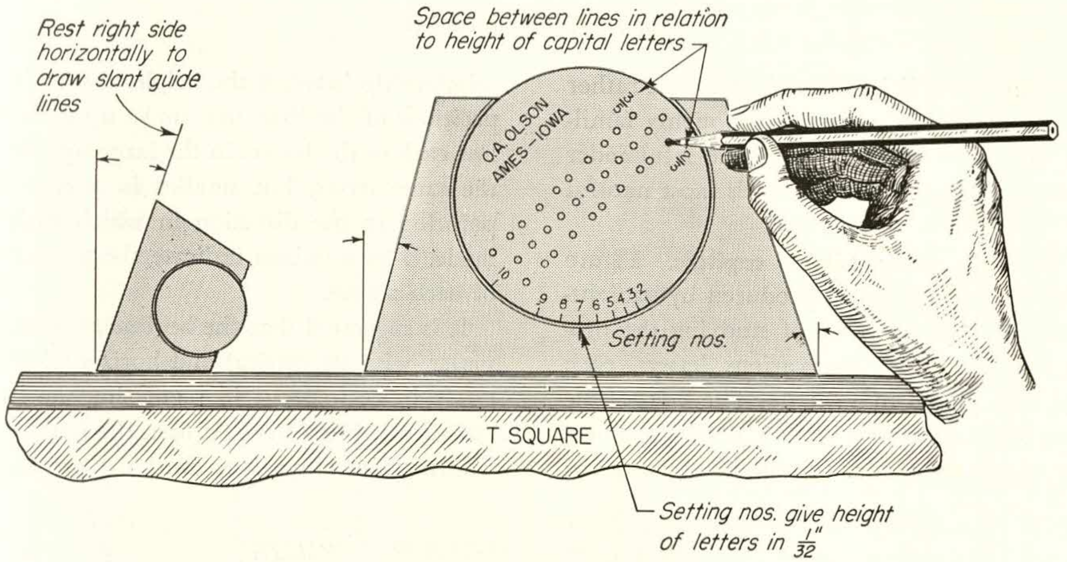

Rest right side horizontally to draw slant guide lines
Space between lines in relation to height of capital letters
O.A. OLSON AMES—IOWA
2/3 3/5 1/2
10 9 8 7 6 5 4 3 2
Setting nos.
T SQUARE
Setting nos. give height of letters in 1/32"

Fig. 1-7b. Ames lettering instrument.

1-8. Balance and stability. In order to overcome the effect of top-heaviness, the upper portions of certain letters and numerals are made smaller than the lower parts. As Fig. 1-9 illustrates, in drawing the straight-line letters, the cross bars are located slightly above the midline. The midstrokes of letters such as *B* and *E* are drawn shorter than the base strokes. For elliptical forms, the upper ellipse of the letter or figure is usually made a trifle smaller and narrower than the lower part. Rounded and pointed letters create the illusion that they are smaller than their neighbors unless their points or rounded extremities run well into the guide lines (Fig. 1-10).

1-9. The left-handed draftsman. Left-handers should expect no great difficulty learning good lettering. It is true that the material in the following sections is discussed with the right-handed draftsman in mind; however, the basic principles of letter formation are equally applicable for left-handed letterers. In general, the *order* of the letter strokes is the same for both left- and right-handers. The *direction* of the strokes will be different for the left-hander, however, since it is obvious that he

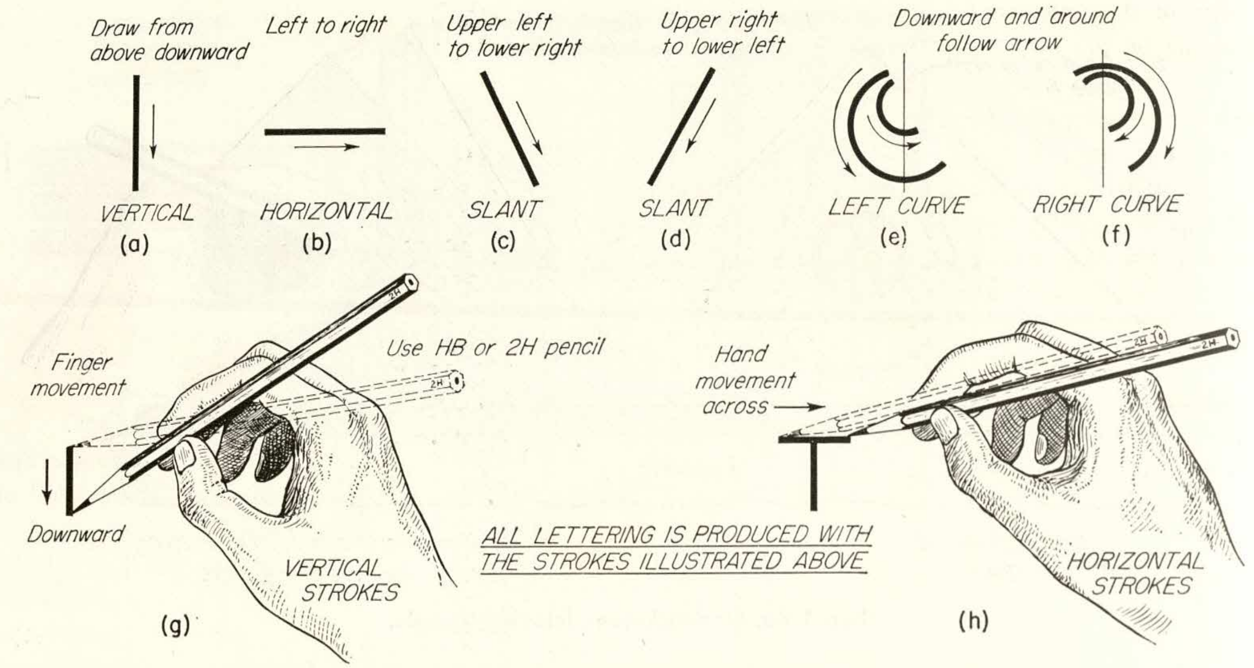


Fig. 1-8. Lettering strokes.

will draw horizontal lines from right to left rather than vice versa. After becoming thoroughly familiar with the forms of the letters, the left-hander should adopt the approach that feels most natural to him.

1-10. Vertical straight-line capitals. Figure 1-11 shows the capital letters produced by straight-line strokes. For the purpose of studying the proportions and design of the various letters, each letter has been placed in a square. The sides of the square are divided equally into six portions. These divisions enable the reader to note at a glance the relationship between the height and width and the positions of the lines that make up each letter. Below each of the letters in the large squares is shown the same letter, but smaller in size, with arrows pointing in the direction in which each stroke is made. The numbers indicate the proper sequence of each stroke.

It is suggested that the beginner use cross-section paper, with its vertical and horizontal lines as the guide lines, to assist in regulating the height and stability of the letters. At first, the letters should be drawn quite large. Not until the proportions and

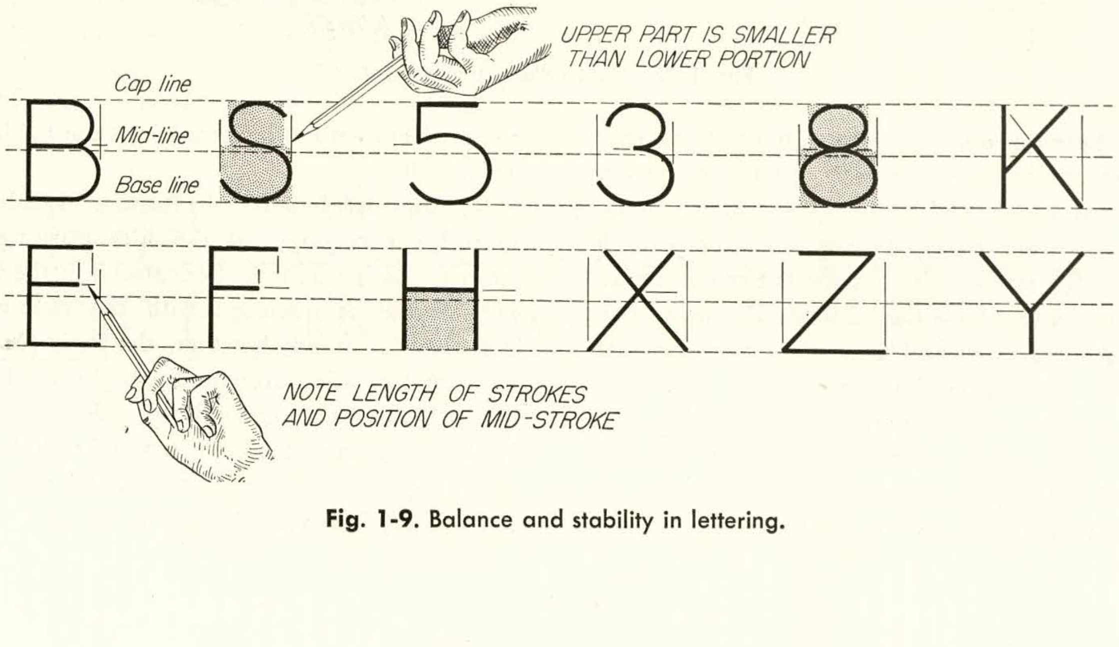

UPPER PART IS SMALLER THAN LOWER PORTION
Cap line
Mid-line
Base line
B
S
5
3
8
K
E
F
H
X
Z
Y
NOTE LENGTH OF STROKES AND POSITION OF MID-STROKE

Fig. 1-9. Balance and stability in lettering.

design of the letters have become familiar should lettering be practiced at the small regular sizes of $\frac{1}{4}$, $\frac{3}{16}$, and $\frac{1}{8}$ in. by using the hand-ruled vertical and horizontal guide lines.

The *I* is made with a vertical downward stroke. The slant strokes of the *A* intersect slightly above the cap line, while its horizontal stroke is placed slightly less than one-third the distance up from the base line. The *T* and *L* consist of vertical and horizontal strokes. The length of the horizontal strokes of the *T* and *L* may be varied to suit the position of the letters in the word (for instance, when a *T* precedes the letter *A,* the horizontal stroke of the *T* should be slightly wider than usual; when an *L* precedes an *A,* the *L*'s horizontal stroke should be narrower than usual).

The middle horizontal stroke of the *H, F,* and *E* are placed just above the midheight line. The length of this stroke in both the *E* and the *F* should be about three-fifths the length of the cap-line stroke. The base-line stroke of the *E* is longer than either its midline or cap-line horizontal strokes. The slant strokes of the *V* intersect slightly below the base line.

The *W* is the widest letter of the alphabet, being $1\frac{1}{3}$ times the width of a normal letter. Its base-line intersections extend below the guide line. The vertical strokes of the *M* and *N* should always be drawn before the slant strokes. The slant strokes of the *M* intersect at the base line. Strokes 2 and 3 of the *N* also intersect at the base line. Note the starting points of the slant strokes of the *X*. The slant strokes intersect just above the midline and finish at the outer corners of the square. The horizontal base line of the *Z* is longer than the cap horizontal line. The slant stroke 2 of the *K* intersects the vertical one-third up from the base line. Stroke 3 starts at stroke 2 and is drawn to the right lower corner on a diagonal that would intersect the top of the vertical if extended. The three strokes of the *Y* intersect at a point slightly below the center of the square.

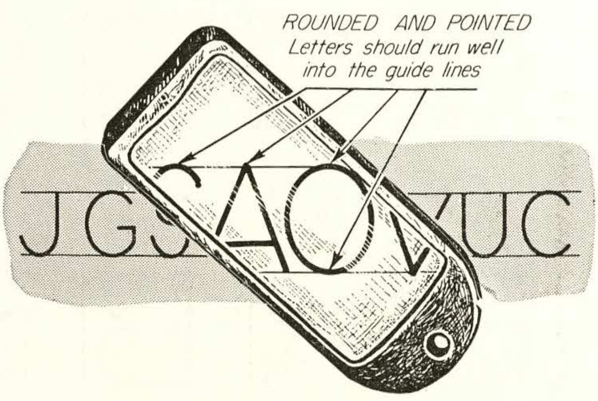


Fig. 1-10. Treatment of rounded and pointed letters.

1-11. The curved and straight-line combinations. Curved letters and letters that are made up of a combination of straight and curved lines are shown in Fig. 1-12. The *O* and *Q* are complete circles. The tail of the *Q* is a short slant line and is placed so that it appears to steady the letter. It

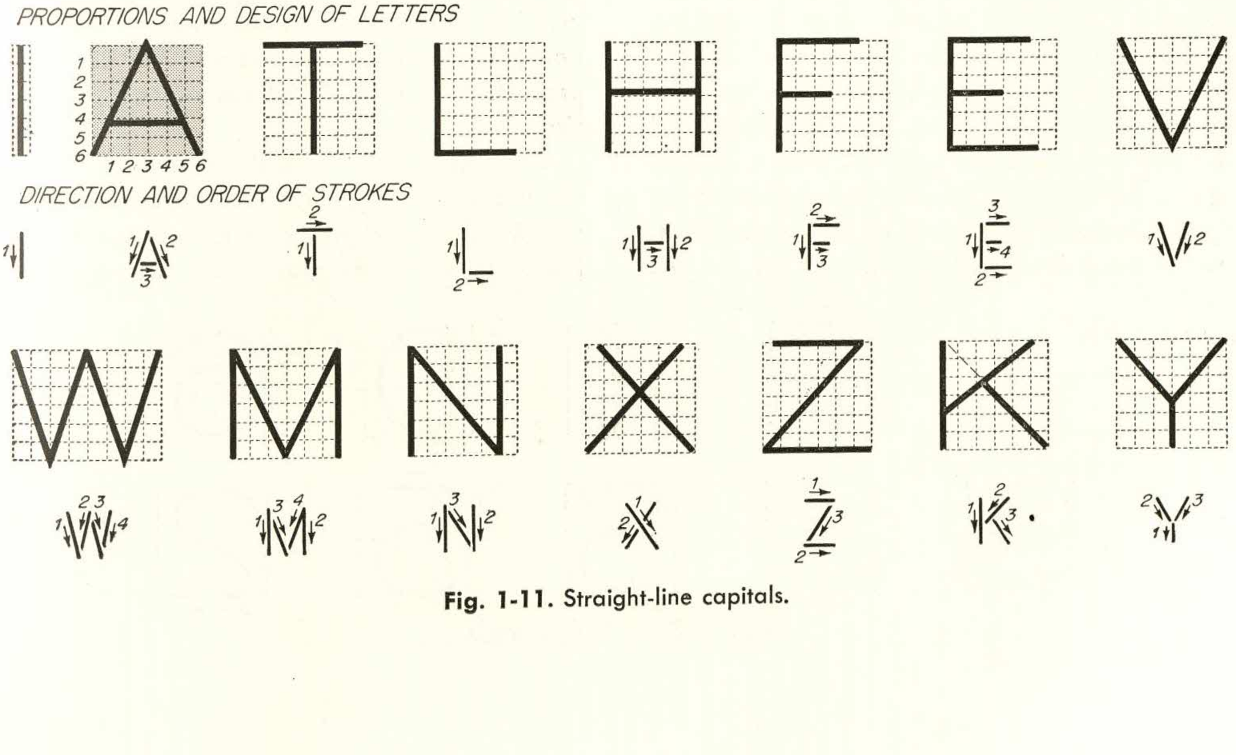

PROPORTIONS AND DESIGN OF LETTERS
1
2
3
4
5
6
1 2 3 4 5 6
DIRECTION AND ORDER OF STROKES

Fig. 1-11. Straight-line capitals.

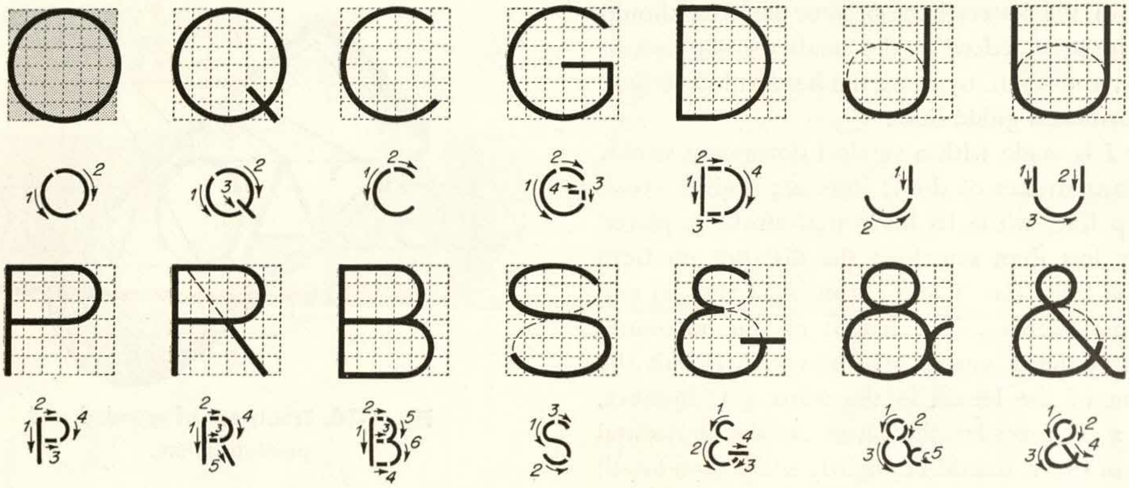


Fig. 1-12. Curved and curved straight-line combinations.

makes an angle of about 45° with the horizontal base line. The *C* and *G* are also circular in design, but they are not the full width of the square. The vertical and horizontal strokes of the *G* may be considered as additions to the letter *C*. The horizontal stroke lies on the midline and starts at the center of the circle. Note that the *O*, *Q*, *C*, and *G* extend very slightly above and below the outline of the square.

The *D* is made with one vertical, two horizontal, and a curved stroke. The curved stroke 4 is a portion of a circle. The *J* consists of a vertical stroke and an elliptical stroke. The half-ellipse stroke is one-third the height of the letter. The *U* is similar in construction to the *J* but is slightly wider.

The letter *P* is made with four strokes. Horizontal stroke 3 should be slightly below the midline and the same length as stroke 2. Stroke 4 is circular. The *R* is similar to the *P*. Horizontal stroke 3 of the *R* rests in the midline. Note the direction of the slant stroke and the fact that it ends beyond the circular stroke 4. The letter *B* is made with six strokes. Strokes 2 and 3 are of the same length, while stroke 4 is slightly longer. Stroke 3 lies just above the midline. Strokes 5 and 6 are elliptical. The strokes of the *S* form ellipses, the upper one smaller than the lower, with the curves extending very slightly above and below the guide lines. The ellipses are tangent just above the center line. Three varieties of the ampersand (&) are shown. The basic construction of each involves a small upper and a large lower ellipse. The ampersand on the right is the American Standard.

1-12. Vertical numerals. As in the case of letters, horizontal and vertical guide lines are drawn for numerals. Figure 1-13 shows the numerals in squares as an aid to the beginner in the study of the construction and proportions of the individual figures. Numerals should never be crowded or made too small for easy legibility. The need for careful study of the sequence and direction of the strokes required and the design and proportion of each figure cannot be overemphasized.

All the numerals, with the exception of the *1*, are five units wide. The *1* is made like the *I*, a downward vertical stroke. The *7* is made with a horizontal and a straight slant stroke ending below

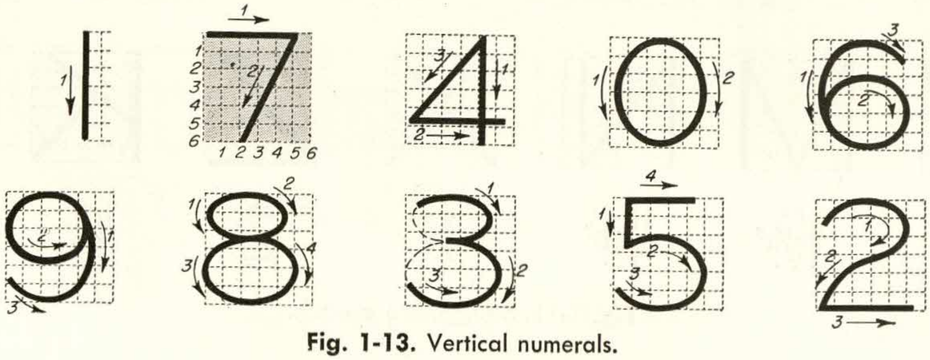


Fig. 1-13. Vertical numerals.

and to the left of the middle of the horizontal stroke. The *4* is made up of three strokes, with the horizontal stroke about one-quarter up from the base line. The zero (*0*) is elliptical, as distinguished from the letter *O*, which is circular. The *6* and *9* are of the same elliptical construction as the zero, the loops being two-thirds the height of the figures. The *6* is a *9* upside down. The *8* is made up of a small ellipse on top of a larger one. The ellipses are tangent just above the midline. The *3* is constructed like the *8* but has the left portions of the ellipses lopped off. The ellipse of the *5* is two-thirds the height of the figure and is wider than the horizontal stroke. The *2* is made with three strokes. Stroke 1 is part of an ellipse, stroke 2 part of a circle, and stroke 3 a horizontal line lying in the base line. Notice that the elliptical and circular strokes are tangent at the midline.

1-13. Vertical fractions. The full height of a fraction is twice that of a whole number (see Fig. 1-14). The midline serves as the position for the crossbar, which is always drawn horizontally. The numerals in the fraction are three-fourths the height of a whole number and are centered about a common vertical. The fraction bar extends slightly beyond the numerals. Five horizontal guide lines are required for lettering fractions appearing alone; seven are necessary when whole numbers and fractions occur together.

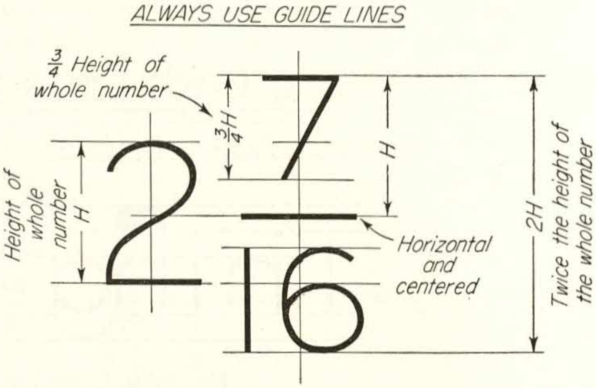


Fig. 1-14. Whole numbers and fractions.

1-14. Vertical lower-case letters. Lower-case letters are rarely used in machine drawing. They are used frequently, however, in map drawing and graphical computations. Like the capitals, the fundamentals of their design are based on the circle, the circle arc, and the straight line. The body of a lower-case letter is two-thirds the height of a capital (see Fig. 1-15). Four horizontal guide lines are used for the construction of the lower-case letters. The body lies between the middle two,

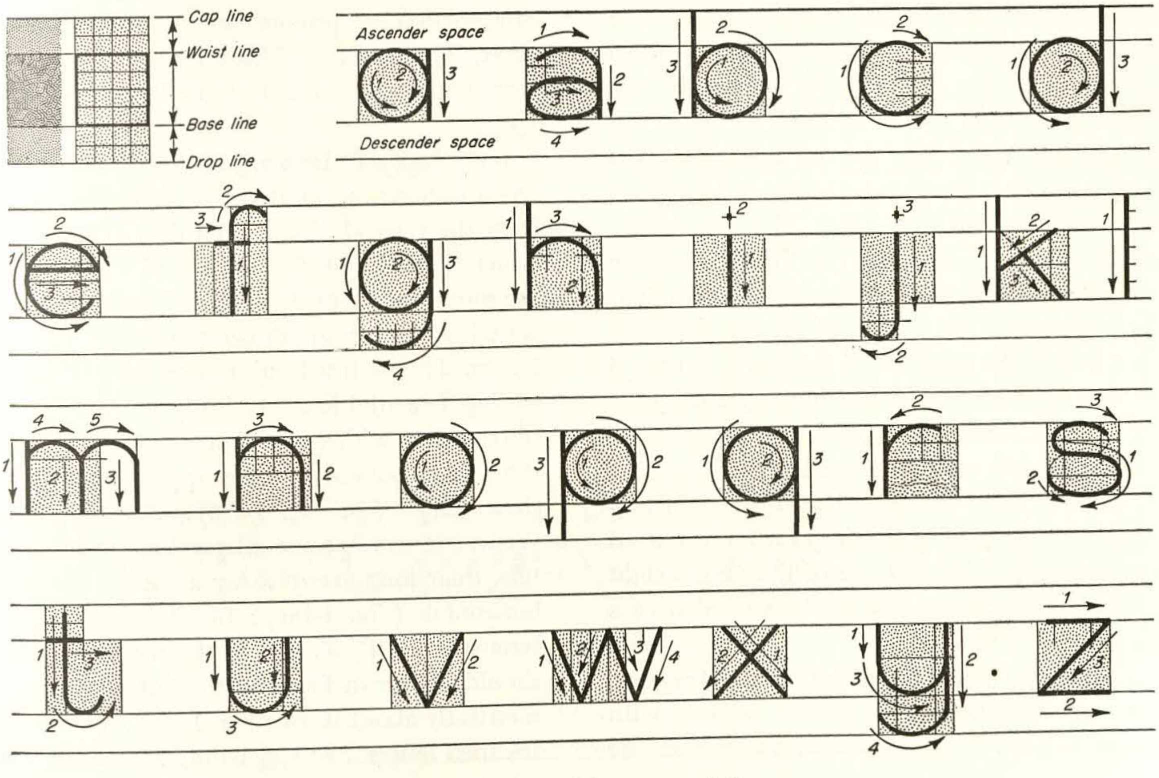


Fig. 1-15. Vertical lower-case letters.

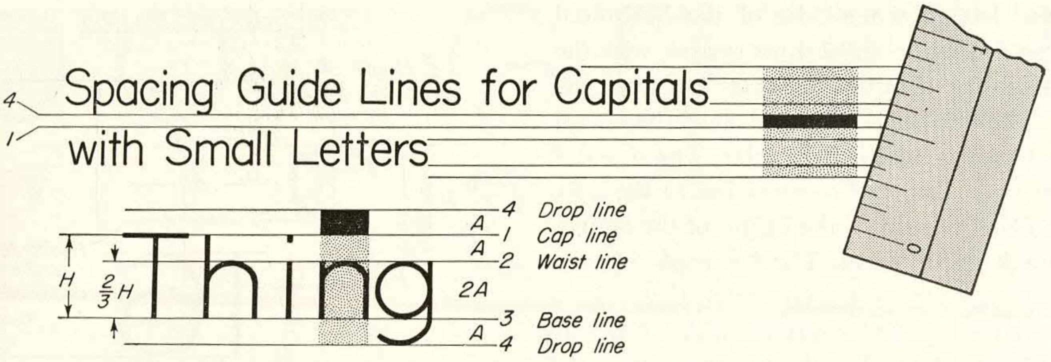


Fig. 1-16. Capital and lower-case combinations.

the top line indicates the height of the ascenders, and the bottom line marks the extent of the drop of the descenders below the base line. As with capital letters, random vertical guide lines should be included.

As shown in Fig. 1-15, all descenders should meet the drop line, and, with the exception of the *t,* all ascenders should reach the cap line. The dots for the *i* and the *j* are located just below the cap line. The horizontal crosses for the *f* and *t* lie on the waist line and extend the same distance on either side of the vertical stroke. Note that the vertical strokes of the *a, b, d, g, p,* and *q* join with the circular strokes and do not tend to widen the appearance of the letter at the tangent point. The descending curves of the *g, j,* and *y* touch the drop line. The ascending curve of the *f* touches the cap line. The horizontal stroke of the *e* is above the midline of the body. The curved strokes for the *h, m, n,* and *r* start about two-thirds of the way up between the base and waist lines. The single vertical stroke of the *l* touches the cap line; so does the vertical stroke of the *k*. Note that slant stroke 2 of the *k* starts at the waist line and intersects the vertical just below the midline of the body. Stroke 3 starts from stroke 2 and is drawn along a diagonal that would, if extended, meet the intersection of the vertical stroke and the waist line.

Strokes 3 of both the *p* and *q* are straight and vertical and terminate in the drop line. The curved strokes 2 of the *f, j,* and *t* are of the same height but not of the same breadth as the curved strokes of the other letters.

1-15. Capital and lower-case combinations. Figure 1-16 illustrates the use of capitals with lower-case letters. Four horizontal guide lines are drawn. The capital letter occupies the space between the cap line and the base line. The waist line, which indicates the height of the bodies of the lower-case letters, is located two-thirds the distance up from the base line to the cap line. The spaces for the ascenders and descenders are each one-third the height of the capitals. The space between the lines of lettering should be equal to or slightly greater than the height of the ascenders and descenders. (Referring to the illustration, the spacing between lines 4 and 1 is equal to or greater than the spacing between lines 1 and 2.)

1-16. Capital and small capital combinations. If desired, large and small capitals may be used in combination to produce an attention-demanding effect. The small capitals are drawn two-thirds to three-fourths the height of the large capitals (Fig. 1-17).

1-17. Inclined letters. Inclined, or slant, letters are drawn at an angle of approximately 22½° from the vertical. Aside from this, the design, construction, and order of strokes of the slant letters are quite similar to those of the vertical type. Horizontal guide lines are drawn the same as for vertical letters. The inclined guide lines may be drawn by scaling five divisions vertically and two divisions horizontally with an ordinary scale. The slope of the line produced will be approximately the desired 22½° (see Fig. 1-18*a*). The circles of the vertical letters become ellipses in the inclined letters, their long axes making angles of 45° with the horizontal (Fig. 1-18*b*). In the drawing of such letters as the *V, X,* and *Y,* the inclined guide line should be drawn first and the letter balanced symmetrically about it (see Fig. 1-18*c*). The lower-case inclined letters (see Fig. 1-18*d*) are drawn with the same proportions and order of strokes as the vertical lower-case letters. They are formed on the same principles as the inclined capital letters.

Inclined numerals and fractions are based on the vertical figures and are drawn in the same fashion as the inclined letters. Care should be used in lettering fractions to be sure that the figures are balanced symmetrically about the slope line and that they have the proper slant. The crossbar is always horizontal.

A complete alphabet of the inclined letters and numerals is shown in Fig. 1-19.

1-18. Spacing letters in words. In spacing letters in words, the areas between the letters rather than the clearances should appear approximately uniform (see Fig. 1-20*a* and *b*). A word appears as a unit when the areas between its component letters are equal or nearly so (as in Fig. 1-20*b* and *d*). Note in Fig. 1-20*a* how the *L* seems to pull away from the *IFE,* even though its actual clearance with the *I* is the same as the clearance between the *I* and the *F* and the *F* and the *E*. At (*b*), the in-between areas are better balanced, and the whole word holds together as a unit. At (*c*), note how the word *BITTER* seems to fall apart at a point between the *T*'s. The letter *B* appears too close to the *I*. At (*d*), with a proper balance of the in-between areas and a disregard of the clearances between the individual letters, the letters combine into a well-knit unit. A little practice is required to avoid the common fault of spacing letters too far apart.

Although no definite rules can be set up for word spacing, the distance between words ordinarily should be approximately equal to the width of the letter *M* (Fig. 1-21*a*). This same distance should be used to separate the comma and the period from the first letter of the following word on the same line (Fig. 1-21*b*). (It should be mentioned here, however, that punctuation marks should be used very sparingly on engineering drawings.)

1-19. Arrangement of title blocks. A title form should appear on all drawings. The descriptive title block is shown in Fig. 1-22*b* to *d*. (For complete information on size, arrangement, and spacing of the title block see Fig. 13-4.) The block is composed symmetrically about a center line as shown in Fig. 1-22. In many industrial concerns, the title block is printed on the drawing sheet. Obviously, the title and important details should occupy the more prominent positions. Capital letters should be used for all lettering in the title block.

1-20. Lettering procedure. Since in industry practically all drawings are now produced on tracing paper or tracing cloth, the problem of arranging and spacing the lettering for titles, notes, specifications, etc., has lost much of its challenge. Because the drawing sheet can be seen through,

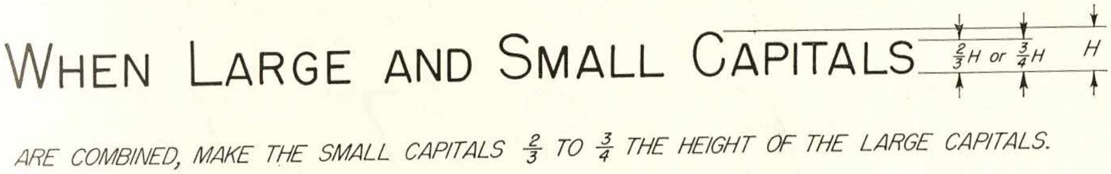

WHEN LARGE AND SMALL CAPITALS
2/3H or 3/4H
H
ARE COMBINED, MAKE THE SMALL CAPITALS 2/3 TO 3/4 THE HEIGHT OF THE LARGE CAPITALS.

Fig. 1-17. Combining large and small capitals.

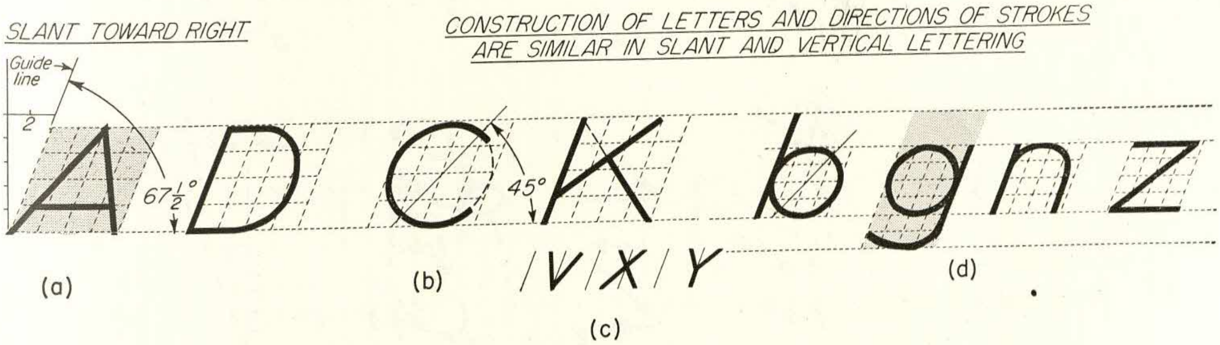

SLANT TOWARD RIGHT
Guide line
2
67½°
A D
(a)
CONSTRUCTION OF LETTERS AND DIRECTIONS OF STROKES ARE SIMILAR IN SLANT AND VERTICAL LETTERING
C K
45°
(b)
/V/X/Y
(c)
b g n z
(d)

Fig. 1-18. Construction of slant capital and lower-case letters.

trial lettering and spacing may be done on a piece of spare paper and then slipped under the drawing sheet and traced. A quick and easy method is illustrated in Fig. 1-23. Fix a scrap of tracing paper over the space the lettering will ultimately occupy. Draw the horizontal and vertical guide lines to ensure proper height and verticality. Next, space the letters into the desired words and the words into the required phrase or sentence. Once a pleasing arrangement has been made, slip the scrap with the trial lettering under the drawing sheet. If the phrase or sentence is to be centered, the midpoint should be marked on the scrap and then aligned with the midpoint on the drawing sheet; otherwise, the phrase may be placed in any position that appears suitable.

If the drawing sheet is opaque, the scrap sheet may still be utilized for arranging and spacing purposes in any number of ways that will come to the draftsman's mind as he moves his scrap trial sheet over the drawing and perceives the relation of the available lettering spaces to his trial lettering.

To overcome the stilted results inevitable when a standard design for each letter is employed, the clever draftsman will develop a pleasing pattern and style by learning to vary the horizontal, vertical, slanting, and elliptical lines to suit the special

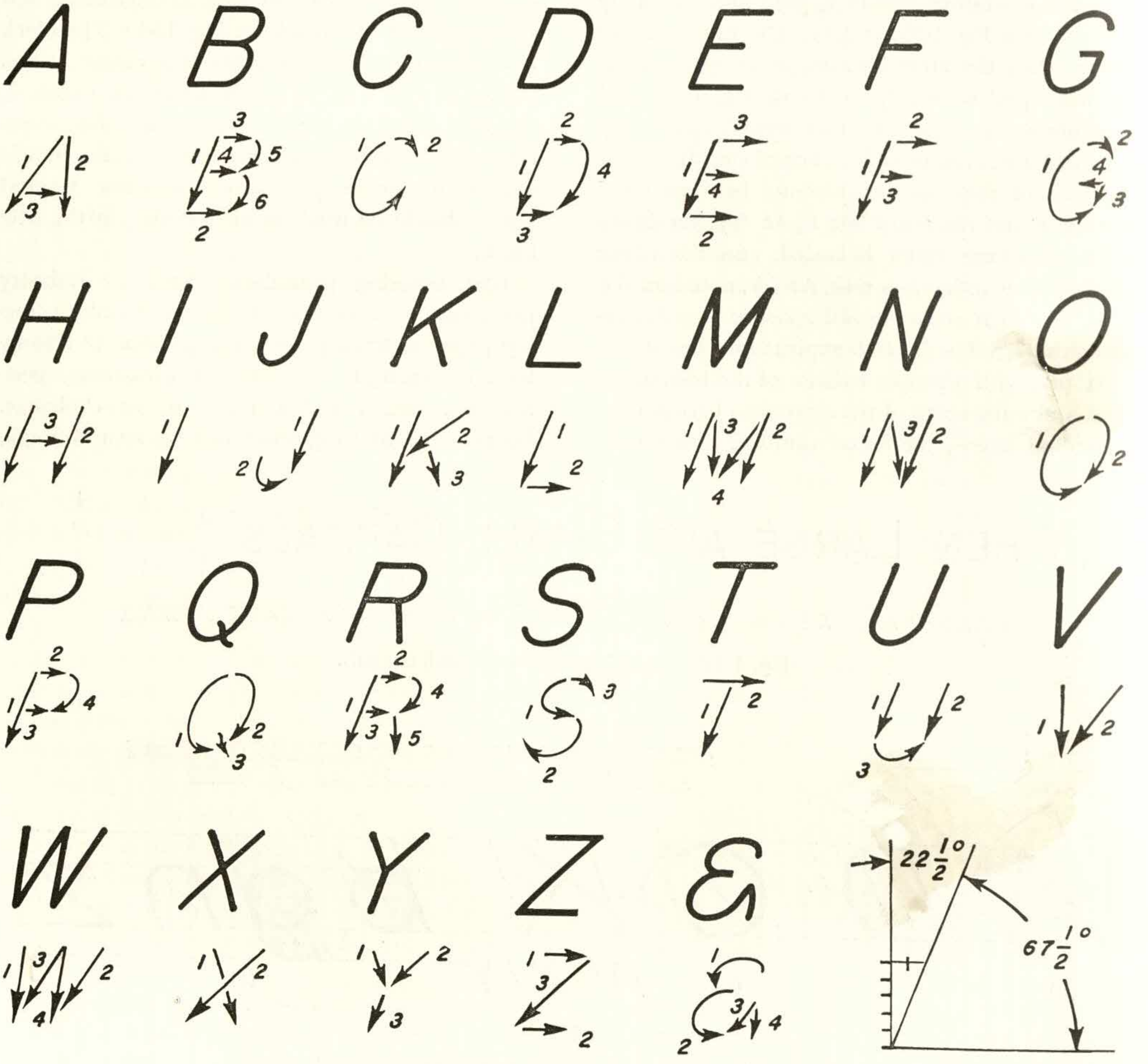


Fig. 1-19a. Inclined capitals.

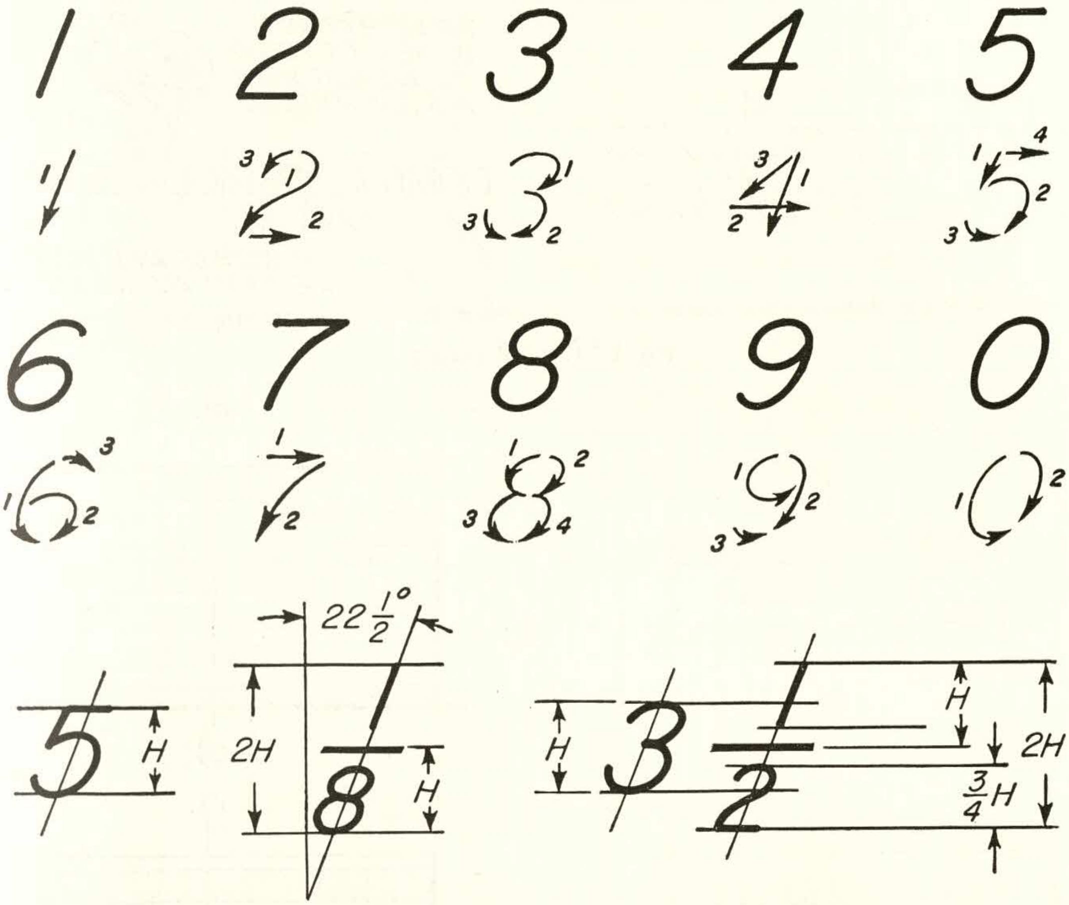
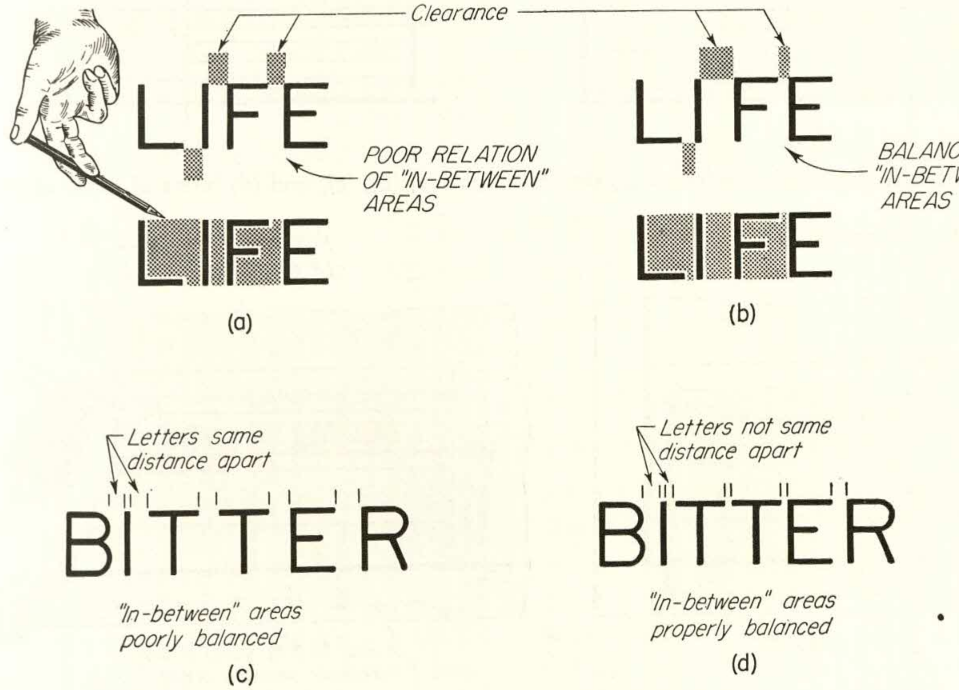


Fig. 1-19*b*. Inclined numerals and fractions.


Clearance
LIFE
POOR RELATION OF "IN-BETWEEN" AREAS
BALANCED "IN-BETWEEN" AREAS
Letters same distance apart
BITTER
"In-between" areas poorly balanced
Letters not same distance apart
"In-between" areas properly balanced

(a) (b)

(c) (d)

Fig. 1-20. Letter spacing and word construction.

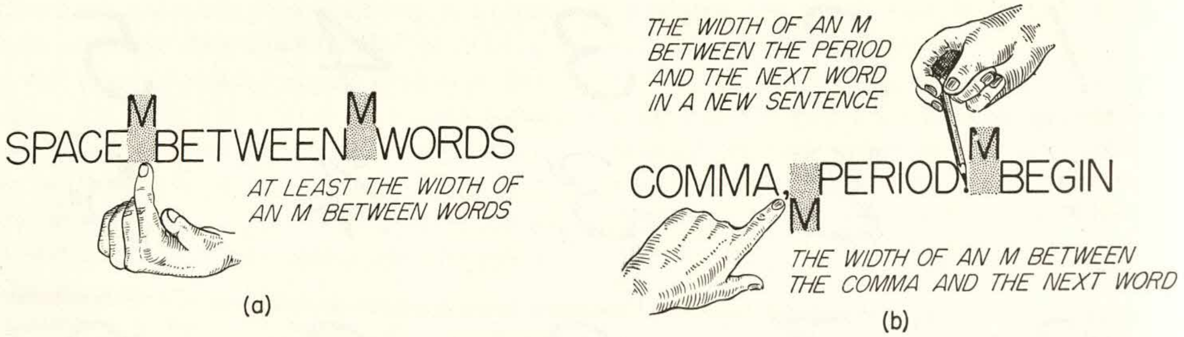

M
SPACE BETWEEN WORDS
M
AT LEAST THE WIDTH OF AN M BETWEEN WORDS
(a)
THE WIDTH OF AN M BETWEEN THE PERIOD AND THE NEXT WORD IN A NEW SENTENCE
M
COMMA, PERIOD. BEGIN
M
THE WIDTH OF AN M BETWEEN THE COMMA AND THE NEXT WORD
(b)

Fig. 1-21. Word spacing.

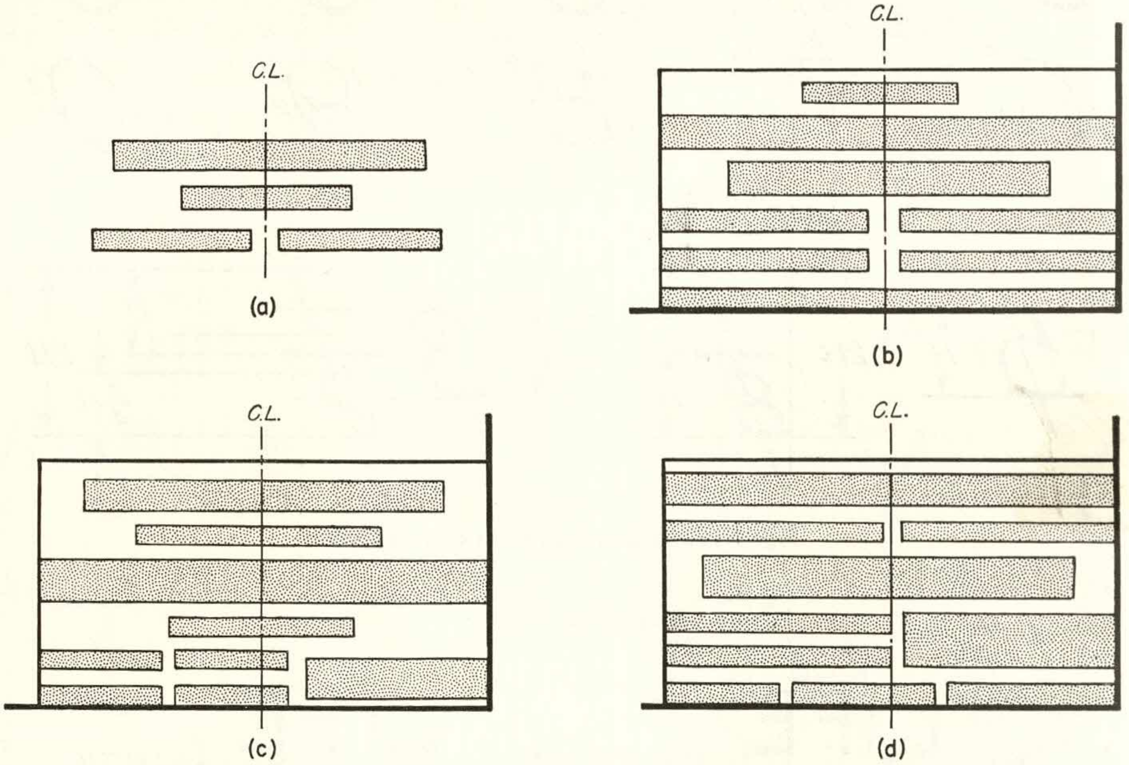


Fig. 1-22. Symmetrical title forms: (*a*) simple detail title; (*b*), (*c*), and (*d*) forms of block titles.

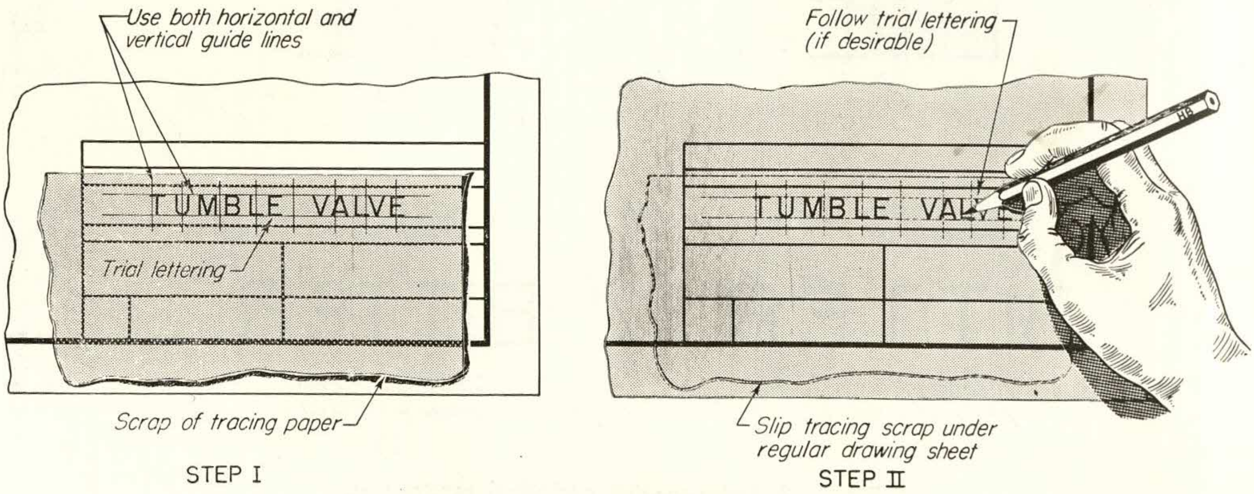
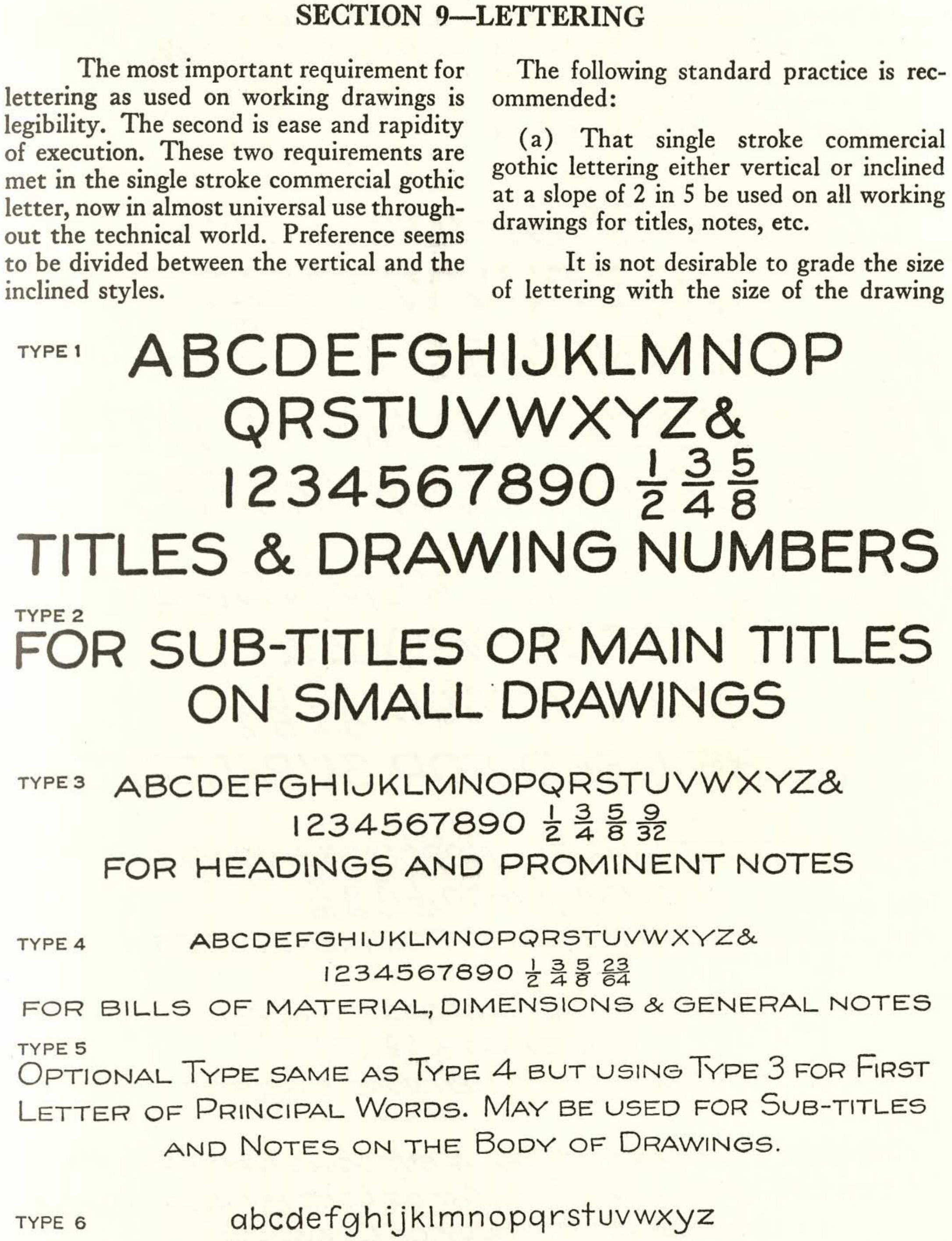

Use both horizontal and vertical guide lines
TUMBLE VALVE
Trial lettering
Scrap of tracing paper
STEP I
Follow trial lettering (if desirable)
TUMBLE VALVE
Slip tracing scrap under regular drawing sheet
STEP II

Fig. 1-23. Arrangement and spacing of lettering in title blocks.



SECTION 9—LETTERING

The most important requirement for lettering as used on working drawings is legibility. The second is ease and rapidity of execution. These two requirements are met in the single stroke commercial gothic letter, now in almost universal use throughout the technical world. Preference seems to be divided between the vertical and the inclined styles.

The following standard practice is recommended:

(a) That single stroke commercial gothic lettering either vertical or inclined at a slope of 2 in 5 be used on all working drawings for titles, notes, etc.

It is not desirable to grade the size of lettering with the size of the drawing

TYPE 1 ABCDEFGHIJKLMNOP
QRSTUVWXYZ&
1234567890 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$
TITLES & DRAWING NUMBERS

TYPE 2
FOR SUB-TITLES OR MAIN TITLES
ON SMALL DRAWINGS

TYPE 3 ABCDEFGHIJKLMNOPQRSTUVWXYZ&
1234567890 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{9}{32}$
FOR HEADINGS AND PROMINENT NOTES

TYPE 4 ABCDEFGHIJKLMNOPQRSTUVWXYZ&
1234567890 $\frac{1}{2}$ $\frac{3}{4}$ $\frac{5}{8}$ $\frac{23}{64}$
FOR BILLS OF MATERIAL, DIMENSIONS & GENERAL NOTES

TYPE 5
Optional Type same as Type 4 but using Type 3 for First
Letter of Principal Words. May be used for Sub-titles
and Notes on the Body of Drawings.

TYPE 6 abcdefghijklmnopqrstuvwxyz

Fig. 1-24. American Standard lettering.

conditions confronting him. This flexibility in lettering style leads to an effect of easy movement and stability throughout the complete word, phrase, and sentence.

1-21. American Standard lettering. Vertical and slant lettering, with its various sizes and uses and other special recommendations of the American Standards Association, are shown in Figs. 1-24 and 1-25. Note particularly the statement, "It is not desirable to grade the size of lettering with the size of the drawing except when a reduced photographic reproduction of the drawing is to be made."

1-22. Special lettering devices. There are several lettering aids on the market that make it possible to produce lettering other than by freehand.

except when a reduced photographic reproduction of the drawing is to be made. In other words the size and weight of the lettering should be such as will produce legible prints from tracings either in pencil or in ink.

Lettering should not be underlined except for particular emphasis.

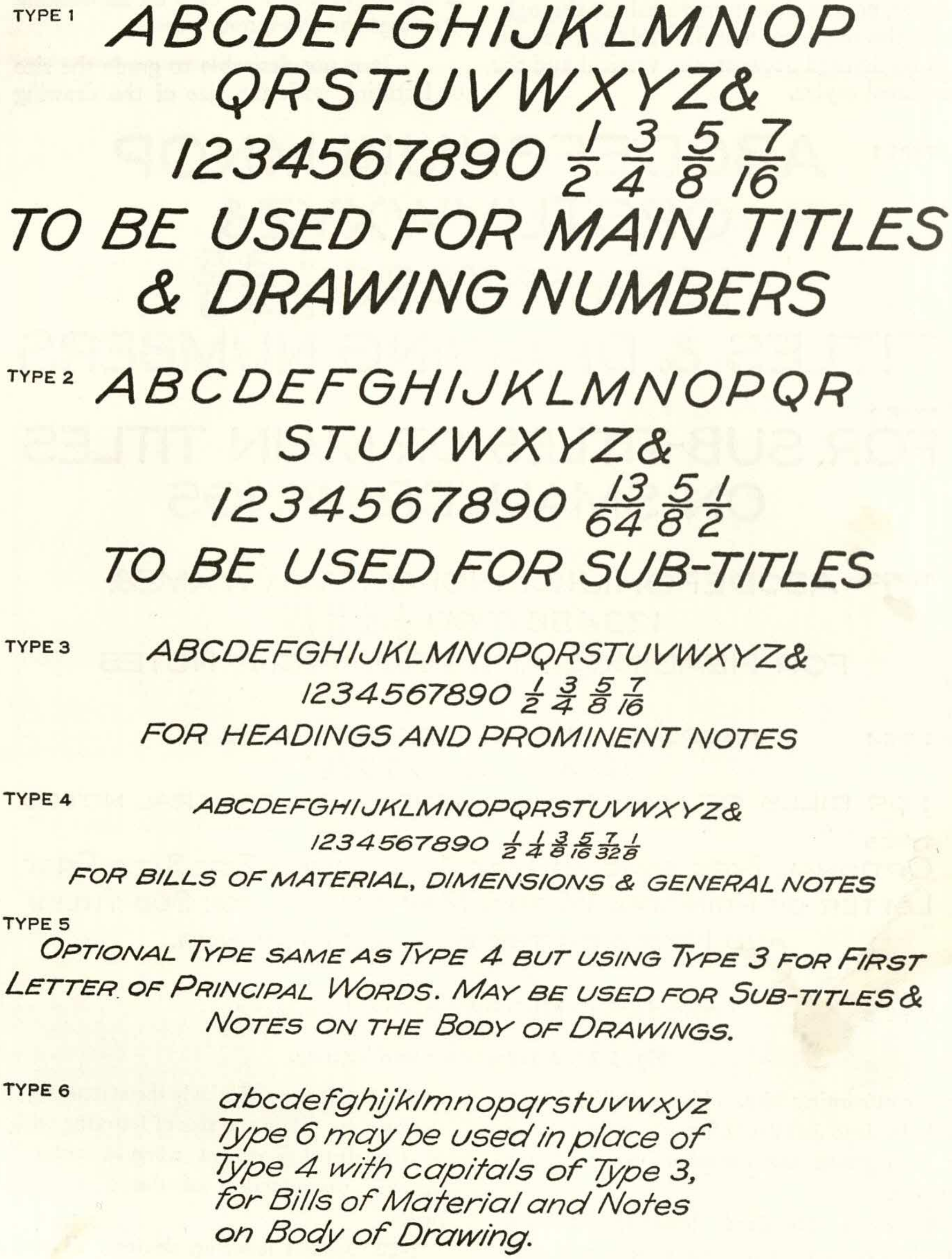

TYPE 1
ABCDEFGHIJKLMNOP
QRSTUVWXYZ&
1234567890 1/2 3/4 5/8 7/16
TO BE USED FOR MAIN TITLES
& DRAWING NUMBERS
TYPE 2
ABCDEFGHIJKLMNOPQR
STUVWXYZ&
1234567890 13/64 5/8 1/2
TO BE USED FOR SUB-TITLES
TYPE 3
ABCDEFGHIJKLMNOPQRSTUVWXYZ&
1234567890 1/2 3/4 5/8 7/16
FOR HEADINGS AND PROMINENT NOTES
TYPE 4
ABCDEFGHIJKLMNOPQRSTUVWXYZ&
1234567890 1/2 1/4 3/8 5/16 7/32 1/8
FOR BILLS OF MATERIAL, DIMENSIONS & GENERAL NOTES
TYPE 5
Optional Type same as Type 4 but using Type 3 for First Letter of Principal Words. May be used for Sub-titles & Notes on the Body of Drawings.
TYPE 6
abcdefghijklmnopqrstuvwxyz
Type 6 may be used in place of Type 4 with capitals of Type 3, for Bills of Material and Notes on Body of Drawing.

Fig. 1-25. American Standard lettering.

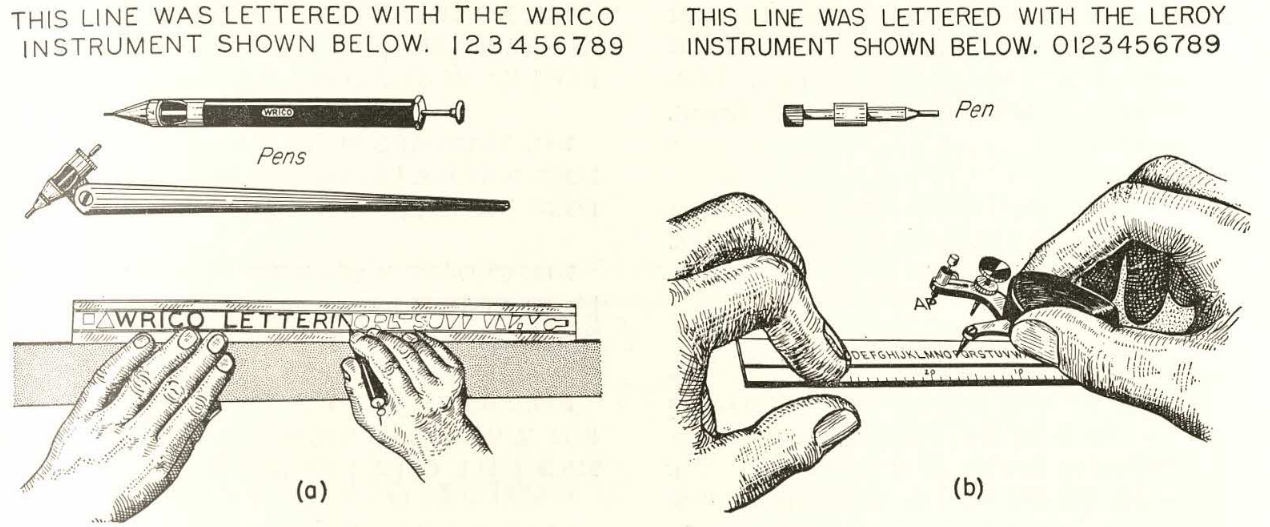

THIS LINE WAS LETTERED WITH THE WRICO INSTRUMENT SHOWN BELOW. 123456789
THIS LINE WAS LETTERED WITH THE LEROY INSTRUMENT SHOWN BELOW. 0123456789
Pens
WRICO
WRICO LETTERING
Pen
(a)
(b)

Fig. 1-26. (*a*) Wrico lettering device; (*b*) LeRoy lettering device.

In using these devices, guide lines are dispensed with, although it is still necessary to understand the fundamentals of spacing. Whereas the result secured through mechanical lettering appears stiff and unartistic, it is always preferable to careless or unskilled freehand work.

Figure 1-26*a* shows the Wrico lettering device with two types of available pens, the template and the guide. The template is a plastic stencil in which have been cut various partial and complete letters. The partial letters may be completed by other letter elements cut into the template. The letters are made by sliding the template back and forth along its grooved retaining guide. A sample line of lettering produced by this instrument is shown at the top of the illustration. Templates containing various different styles of letters and of figures running up to 1 in. in height are readily available.

Figure 1-26*b* shows the LeRoy lettering instrument and the type of point used with it. This device consists of incised letters on a guide which can be moved along a straightedge (the T square). A pin on the instrument follows the grooved letters on the guide, and the letters are reproduced on the drawing by the scriber. This device can be obtained with a fixed scriber that will produce only vertical letters or an adjustable scriber that can be set to produce either the vertical or slant type. Various guides, with letters and numerals from heights of 0.08 in. up to 2 in. and points making lines of varying thicknesses suitable to the heights of the letters, are available. A sample of lettering produced by this instrument is shown along the top of the illustration.

PROBLEMS

It is recommended that the beginner use cross-section paper and make letters between ½ and 1 in. high while he is learning the construction and order of strokes for the letters, numerals, and fractions. After the individual letters have been practiced, the instructor, at the opening of every laboratory period throughout the whole term, should assign a short sentence exercise that can be lettered in 10 to 15 min. This constant practice will lead to proficiency in the art of lettering. The following exercises are suggested as aids in making assignments.

1-1. Make a suitable layout on a 5½- by 8½-in. sheet with a ½-in. border, spacing the horizontal guide lines to accommodate capital letters ¼ in. high with 3/16-in. spaces between lines. Letter the straight-line letters shown in Fig. 1-11. Fill the sheet.

1-2. Make a suitable layout on a 5½- by 8½-in. sheet with a ½-in. border for capital letters 3/16 in. high with spaces between lines of ⅛ in. Letter the following sentence consisting of straight-line letters only: LET LAX MEN LIVE LAZILY IF THEY WILL. Repeat it, filling the entire sheet.

1-3. Using the layout suggested in Prob. 1-1, letter the curved-line letters shown in Fig. 1-12. Fill the sheet.

1-4. Using the layout suggested in Prob. 1-2, letter the following: JACK SAYS, "POOR LETTERING WILL MAR THE APPEARANCE OF AN OTHERWISE QUITE ACCEPTABLE DRAWING." Repeat, filling the sheet.

1-5. Make a suitable layout on a $5\frac{1}{2}$- by $8\frac{1}{2}$-in. sheet for figures $\frac{1}{8}$ in. high with spaces between lines $\frac{1}{8}$ in., and letter the numerals shown in Fig. 1-13. Repeat, filling the sheet.

1-6. Make a suitable layout on a $5\frac{1}{2}$- by $8\frac{1}{2}$-in. sheet, and letter the following numerals with their fractions (whole numbers $\frac{1}{8}$ in. high, entire height of fraction $\frac{1}{4}$ in., numbers in fraction about $\frac{3}{32}$ in. high): $2\frac{5}{64}$, $3\frac{3}{32}$, $4\frac{9}{16}$, $5\frac{1}{2}$, $8\frac{3}{4}$, $9\frac{7}{8}$, $1\frac{1}{8}$, $7\frac{1}{16}$, $10\frac{1}{4}$. Repeat, filling the sheet.

1-7. Letter the following statements:

ENGINEERING DRAWING IS THE GRAPHIC LANGUAGE THE ENGINEER EMPLOYS TO CONVEY HIS THOUGHTS, IDEAS, AND DESIGNS TO OTHERS.

AT LEAST TWO COMPLETE PRINCIPAL VIEWS ARE USUALLY REQUIRED TO CONVEY THE TRUE SHAPE AND SIZE OF AN OBJECT IN ORTHOGRAPHIC PROJECTION DRAWING.

Sheet size, $5\frac{1}{2}$ by $8\frac{1}{2}$ in. Capital letters $\frac{1}{8}$ in. high. Spaces between lines $\frac{3}{32}$ in.

Problems 1-8 to 1-13. Letter the following problems on $5\frac{1}{2}$- by $8\frac{1}{2}$-in. sheets with a $\frac{1}{2}$-in. border. Draw horizontal and vertical guide lines, and show letters and whole numbers $\frac{1}{8}$ in. high, fractions $\frac{1}{4}$ in. high, and space between lines $\frac{3}{32}$ in. If available, a lettering triangle or other guide-line device may be used. Repeat the legends to fill the entire sheet.

1-8. $\frac{1}{2}$ DRILL AND REAM | $\frac{1}{2}$ SPOT-FACE × $\frac{1}{32}$ DEEP | $\frac{5}{16}$ DRILL, 4 HOLES EQUALLY SPACED ON A 3″ B.C. | $\frac{1}{16}$ × 45° CHAMFER, BOTH ENDS.

1-9. $\frac{15}{32}$ DRILL, C'BORE $\frac{5}{8}$ DIA. × $\frac{19}{64}$ DEEP, 5 HOLES | KEYWAY $\frac{1}{4}$ WIDE × $1\frac{1}{2}$ LONG × $\frac{1}{8}$ DEEP | NECK $\frac{1}{8}$ WIDE × $\frac{1}{16}$ DEEP | $\frac{1}{4}$ DRILL, C'SINK 82° × $\frac{1}{2}$ DIA.

1-10. NO. 20 DRILL THROUGH | NO. 4 STANDARD TAPER PIN | NO. 14 PRATT AND WHITNEY KEY | $\frac{1}{4}$ × $1\frac{3}{4}$ STANDARD SQUARE KEY.

1-11. STANDARD PLAIN WASHER | STANDARD LOCK WASHER | KEYWAY $\frac{1}{8}$ WIDE × $\frac{1}{8}$ DEEP × $\frac{5}{8}$ LONG | SEAT FOR WOODRUFF KEY NO. 808.

1-12. GROOVE $\frac{1}{8}$ WIDE TO $1\frac{1}{4}$ DIA. | $\frac{1}{2}$-13 NC-2 | $\frac{7}{16}$-20 NF-3 LH | $\frac{5}{8}$ ACME 8 THDS. PER INCH | $\frac{7}{8}$ SQUARE 6 THDS. PER INCH LH.

1-13. FILLETS AND ROUNDS $\frac{1}{8}$ | FILLETS AND RDS. $\frac{1}{8}$ UNLESS OTHERWISE SPECIFIED | FAO | FINISH ALL OVER | GRIND FINISH.

1-14. Letter the following simple detail titles arranged as shown, making the name of the part $\frac{3}{16}$ in. high, the spaces between lines of lettering $\frac{1}{8}$ in., and the height of all other letters in the title $\frac{1}{8}$ in. high:

MOTOR BRACKET
SCALE FULL SIZE
CAST IRON 1 R'QD

VISE JAW
SCALE HALF SIZE
WROUGHT IRON 1 R'QD

TOOL GUIDE
SCALE $\frac{1}{4}'' = 1''$
CAST IRON 1 R'QD

HANGER BRACKET
SCALE 1 = 1
ALUMINUM 1 R'QD

1-15. Make a layout as suggested by the dimensions given in Fig. 13-4, and letter the following title block:

NAME OF YOUR INSTITUTION OR COMPANY
CITY WHERE LOCATED
JIG ASSEMBLY

DATE	SCALE 1 = 1	DRAWING NO.
DR. BY	TR. BY	
CH. BY	APP. BY	

9067

Chapter 2

ORTHOGRAPHIC PROJECTION

Practically speaking, all objects that the draftsman is called upon to draw are three-dimensional. In pictorial drawing, it is customary to represent the three dimensions by shading and perspective. Such techniques are not satisfactory for working drawings, however, since they cannot convey accurately the constructional features of the object. The draftsman's problem, then, is to represent three-dimensional parts and forms on the flat plane of the drawing paper in such a way that all features are shown in their true dimensions and in their true relationship to other features on the part. To do this, the draftsman must draw a number of views of the part from different angles and employ what is known as *orthographic projection.*

Orthographic projection means right-angular, or perpendicular, projection, and its principles may be readily understood by referring to Fig. 2-1. If

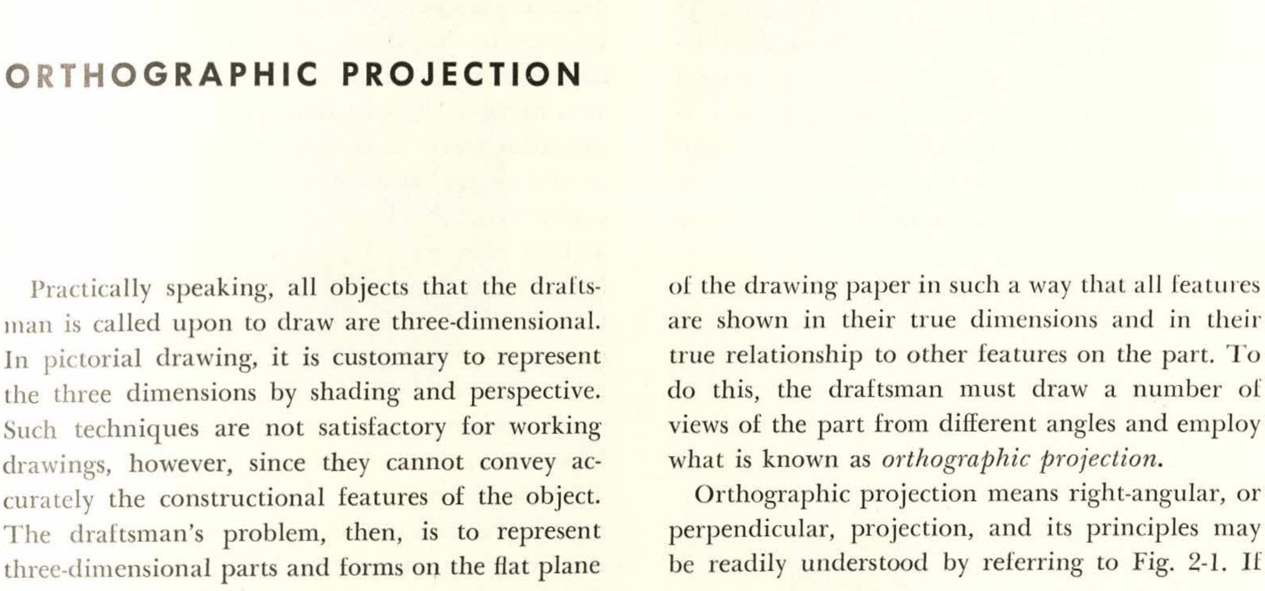


Fig. 2-1. Orthographic projection.

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Calcutta
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S.C.E.R.T West Bengal
Date........................
Acc No 5643

it is imagined that an object is being viewed by an observer standing an infinite distance from it and that a transparent plane is placed between him and the object, the projectors (or perpendiculars) from the points on the object would carry the image to the plane without distortion because the projectors are all parallel to each other and perpendicular to the image, or picture, plane. The diminishing effects of perspective are absent in orthographic projection.

In Fig. 2-1, it will be noted that point 1 on the object appears as point 1 on the image plane. Point 2 appears as shown, and all the other points on the object project as illustrated to form the complete image. Note that, on the object, line 2-3 is on a slant with line 1-2, while on the image plane it is perpendicular. The complete image or view formed always shows the outline of the object and the intersections of its various surfaces as seen from one direction.

2-1. Hidden details. In drawing an orthographic view, it is customary to represent all edges and intersections of a part even though some features may not be visible from the direction in which the view was taken. The hidden features are shown by lines made up of short dashes, called "hidden" lines (see Sec. 3-7). If a hidden line coincides with an external contour line, the hidden line is not shown (see Fig. 3-9).

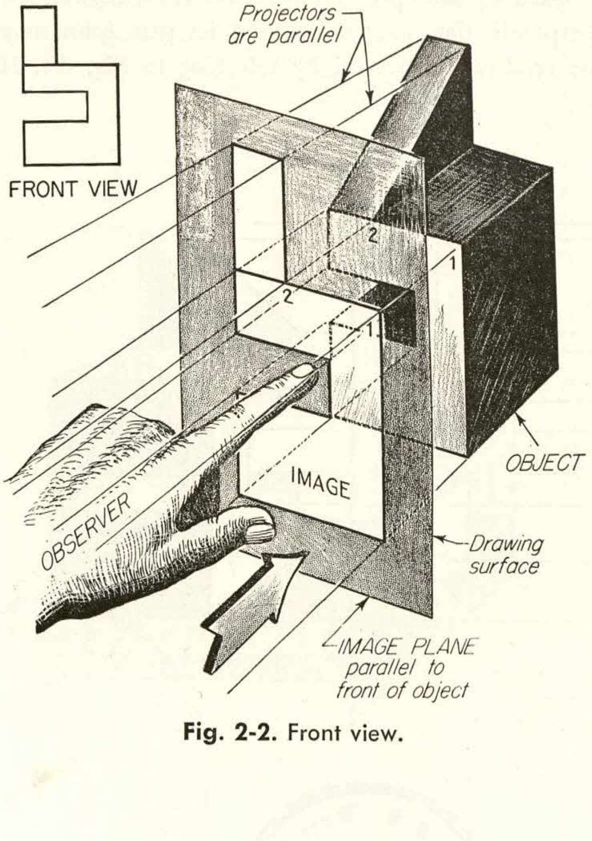


Fig. 2-2. Front view.

2-2. The primary planes and views. There are six principal, or primary, views, corresponding to the six principal planes of projection. These are the front, back, top, bottom, left-, and right-side views (Fig. 2-11).

2-3. Choice of views and related views. As mentioned above, it is almost always necessary to show more than one view of an object in order to describe completely its features and dimensions. In selecting the views, an orderly procedure and arrangement are always followed. After the first view has been chosen (usually the front view), each succeeding view is considered as being projected to and drawn on an image plane that is at right angles to the previously drawn view (see Figs. 2-5 and 2-6, for example). A view that is projected from another view is said to be adjacent to the latter view. Generally, two adjacent views only are required to describe a simple object; a more complicated piece may require three, perhaps four, and sometimes five or more views for complete and satisfactory description.

Of the six principal views, however, only three are usually employed in actual practice. These are the front, top, and right-side views. The three remaining principal views—the left-side, rear, and bottom—are used only when special need calls for any one or more of them.

2-4. Front view. The front view should show the most characteristic shape of the object or its natural appearance when observed in its permanent, or fixed, position. Because most parts used in mechanisms are small and may be viewed in any manner, it is permissible to use the view that shows the salient features of the part and the least number of hidden lines as the front view. The front view is always considered as lying in the plane of the paper, while all other views are rotated into this plane. To draw the front view, the image plane is placed parallel to the front face of the object (study Fig. 2-2), and the points of the object are projected perpendicularly to the image plane. The view as it appears on the drawing sheet is shown in the upper left portion of the illustration.

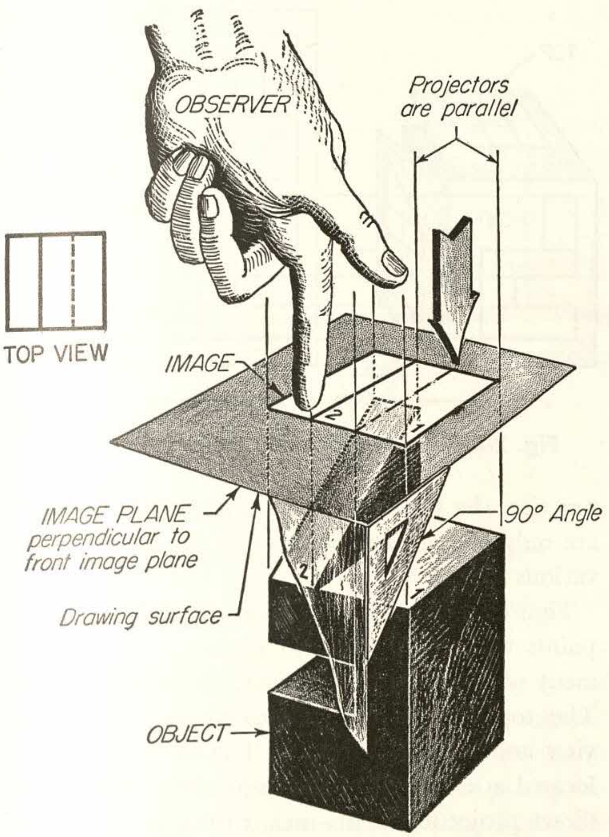


Fig. 2-3. Top view.

2-5. Top view. The top view is projected to and drawn on an image plane above the object. This plane is located at right angles to the front image plane (study Fig. 2-3), and when viewed in the direction of the arrow, the lines and intersections of the object will project the image shown on the image plane. Note that the intersections of invisible surfaces are also projected and represented with hidden lines. The view as it appears normally is shown at the upper left.

2-6. Right-side view. The image plane for the right-side view is located at right angles to both the front image plane and the top image plane, thus making all three image planes mutually perpendicular. Figure 2-4 shows the image on the image plane, and at the upper right is illustrated the right-side view as it appears on the drawing sheet. Here again, the invisible edges of the object are shown as hidden lines in the view.

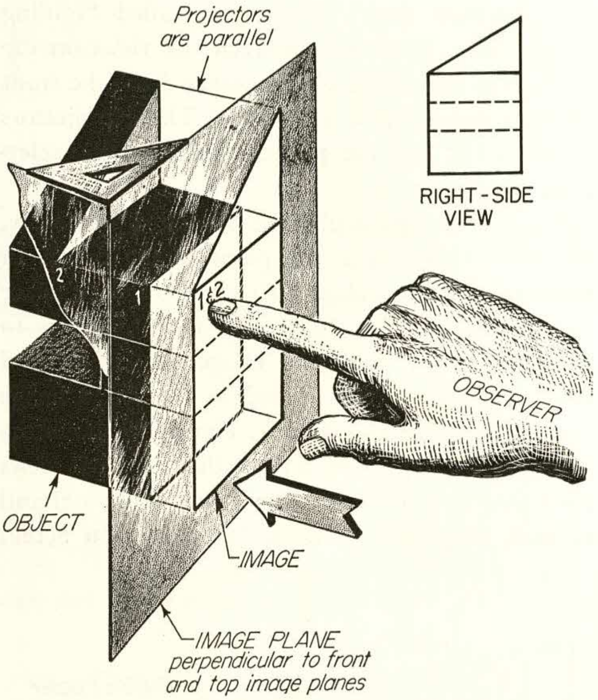


Fig. 2-4. Right-side view.

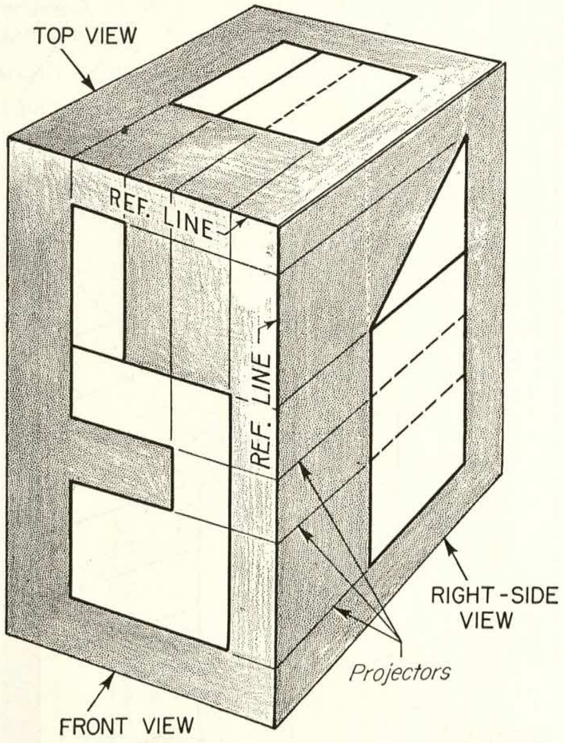


Fig. 2-5. Three views in projection.

2-7. Reference lines. When these three mutually perpendicular image planes are seen together, they may be imagined as forming a boxlike form of transparent material (see Fig. 2-5). The lines of intersection of the image planes are known as "reference lines" (sometimes called "folding lines"). The projectors between the views on the surfaces of the image planes extend from the front view to the top and side views. These projectors always cross, and are perpendicular to, the reference lines.

2-8. Revolving the planes. As noted previously, the front view lies in the plane of the paper. In order to show the other two views on the surface of the drawing sheet, however, it is necessary to revolve the top and side image planes forward as though they were hinged to the front image plane (as shown in Fig. 2-6). Figure 2-7 shows the orthographic representation of the principal views after they have been revolved, with horizontal and vertical projectors included for clarity. In actual practice, the projection lines are never drawn but are only imagined as connecting the points on the various views.

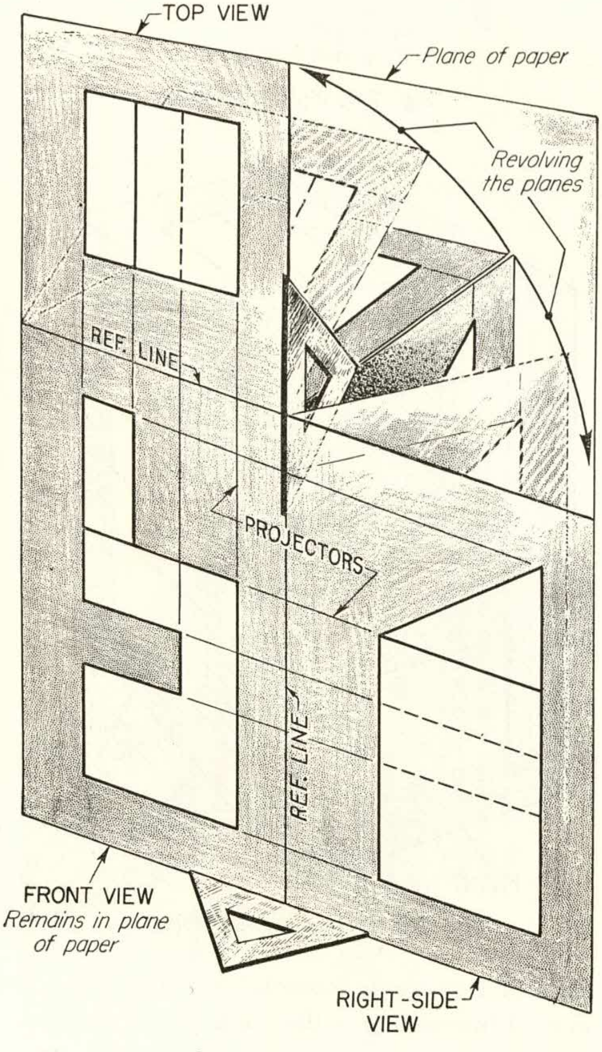


Fig. 2-6. Revolving planes into plane of paper.

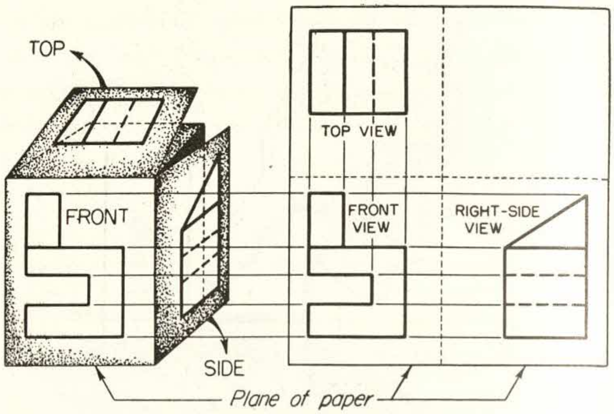


Fig. 2-7. The three views on the drawing sheet.

Figures 2-6 and 2-7 show several significant points to keep in mind in regard to the arrangement of the various views on the drawing sheet. The top view is always located above the front view and projected from it. The right-side view is located at the right of the front view and is also in direct projection. This means that, once the position of the front view has been fixed, the positions of its adjacent views are fixed and cannot be altered (except when the side views are drawn in the alternate position, as discussed in Sec. 2-14). Although the reference, or folding, lines are not always shown on a drawing, they, too, help fix the positions of the views in relation to each other and on the drawing surface, as will be shown in later chapters.

2-9. First- and third-angle projection. Extension of the horizontal and vertical planes of projection as shown in Fig. 2-8 will form four angles that may be numbered as in the illustration. In theory, an object could be placed in any one of these angles and its image drawn on the projection planes, which could then be rotated into the plane of the paper. In actual practice, however, projection in only the first and third angles is practical. *First-angle projection* is almost universally followed in Europe and was used in the United States until around 1890. In principle, projection in the first angle means that when the image planes are revolved into the plane of the paper the top view will appear *below* the front view and the left-side view will appear to the *right* of the front view. The present practice in this country, and the American

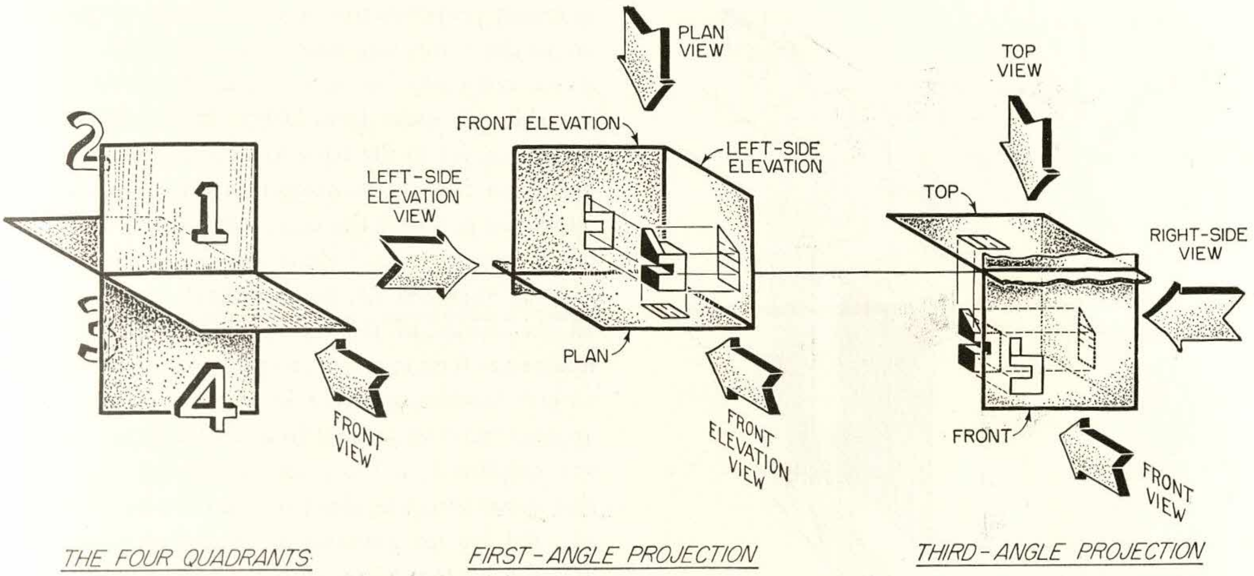


Fig. 2-8. The four quadrants—first-angle and third-angle projections.

Standard, is *third-angle projection.* It is the system of projection used in this chapter and throughout the text. In essence, third-angle projection means that the plane of projection is always placed between the observer and the object (that is, the object is viewed by looking *through* the projection plane).

2-10. The three dimensions. Any orthographic view standing alone, since it is represented on a flat surface, can show only two dimensions. The missing third dimension must be sought in an adjacent view. When looking at the front view (see Fig. 2-9), we see the width and height dimensions of the object, but its depth is seen in the top and side views. The side view shows the height and depth, necessitating reference to the front or top for the width, while the top view shows width and depth dimensions, requiring the front or side to reveal the height.

2-11. Left-side, bottom, and rear views. The three additional principal views are the left-side, bottom, and rear. Their image planes are also

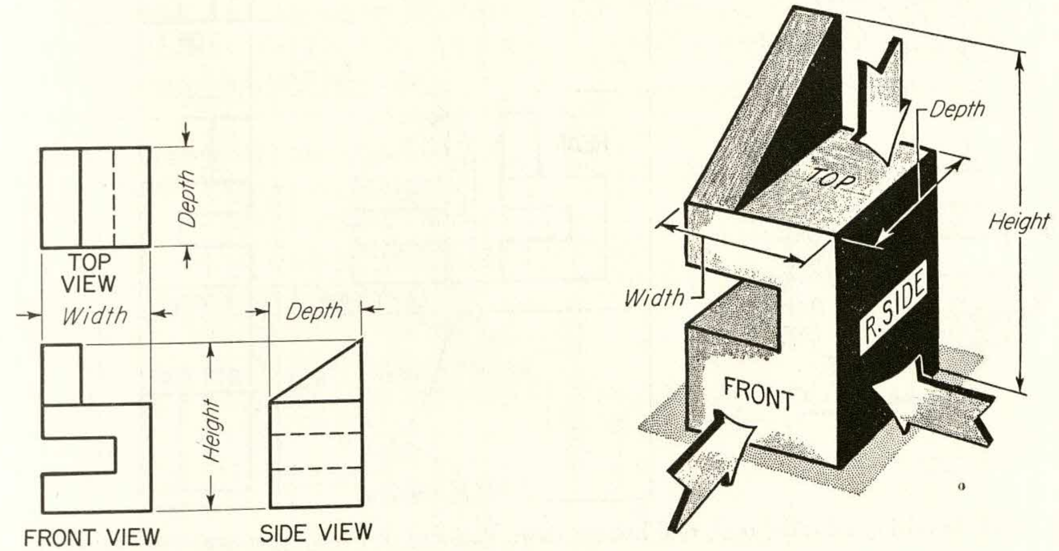


Fig. 2-9. Dimensions in views.

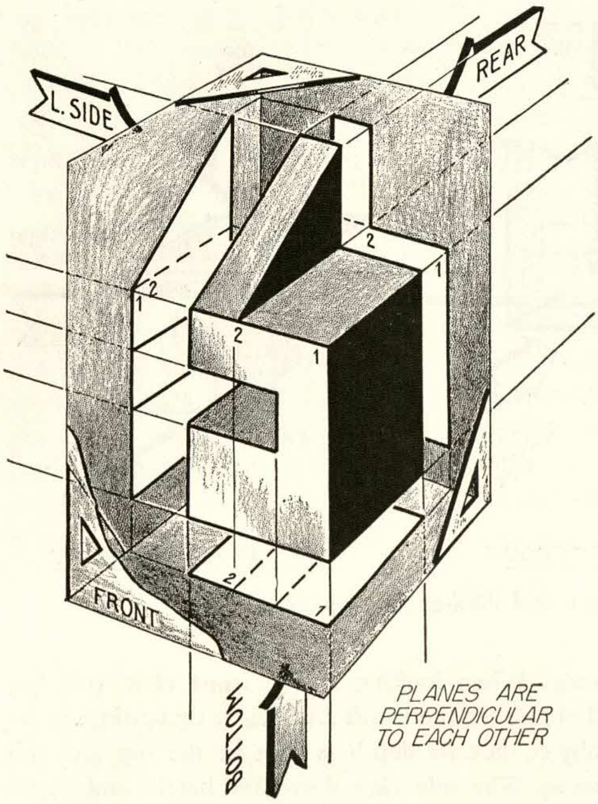


Fig. 2-10. Left-side, bottom, and rear views.

mutually perpendicular and, of course, perpendicular to the front, top, and right-side views. The observer moves to the left of the object to see the left side, he looks from below to see the bottom, and he moves to the back to see the rear view. The points on the object project to the planes of projection in precisely the same way as they do for the other three principal views (see Fig. 2-10).

2-12. Positions of the principal views. When all six planes of projection with their respective images are seen together in space, they form a transparent, boxlike structure in which the object itself appears to be suspended in air. The technique that was employed to bring the front, top, and right-side views into the plane of the drawing surface is adopted for the rotation of the left-side, the rear, and the bottom views into the same plane of the paper. The left-side and bottom views are rotated toward the observer as though hinged to the front view, while the rear view is rotated toward the observer as though hinged to the left-side view (see the left-hand portion of Fig. 2-11). The front view always lies in the plane of the drawing surface and therefore does not require rotating.

The relative positions on the drawing sheet of the six principal views and their relationship to each other are shown at the right in Fig. 2-11. Notice that the front, right-side, left-side, and rear

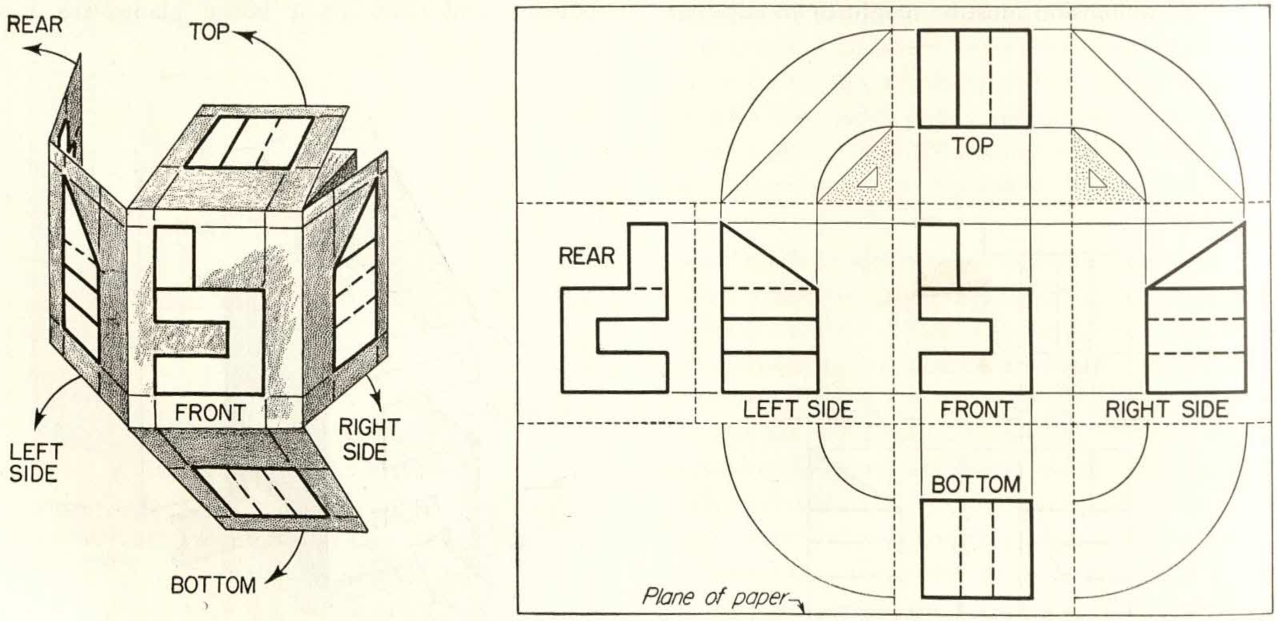


Fig. 2-11. Revolving left-side, rear, and bottom views. Positions of the six principal views on the paper.

views line up in direct horizontal projection; the front, top, and bottom views line up in direct vertical projection. (As noted in Sec. 2-3, any two adjacent views are directly projected from each other.) Each view has two of the three common space dimensions of height, length, and depth, while an adjacent view supplies the missing dimension.

2-13. Use of the miter line. In making an instrument drawing, the use of a miter line offers a convenient method of laying out a third view when two views are in progress. In Fig. 2-12, the front and top are shown. The miter line is drawn to the right of the top view. Moving the miter line (to the right or left) permits control of the distance between the front and side for dimensioning and better layout.

At the left in Fig. 2-13*a*, the front and side are given. A point (2) has been projected upward from the right-side view. The miter line is drawn to intersect this projector. The distance between the front and top views is controlled by the position of the miter line above the side view.

At the right in Fig. 2-13*a*, the top and right side are in progress. The intersection of the projectors of a similar point (2) from the two views locates the required position of the miter line.

If neither dimensioning nor balanced spacing need be considered, the reference lines (folding lines) between the views are placed on the drawing sheet and the miter line is drawn, 45° with a horizontal, through their intersection. Any view of the object may be started and its points projected across the reference lines and the miter line as necessary to aid in completing the other views (see Fig. 2-13*b*).

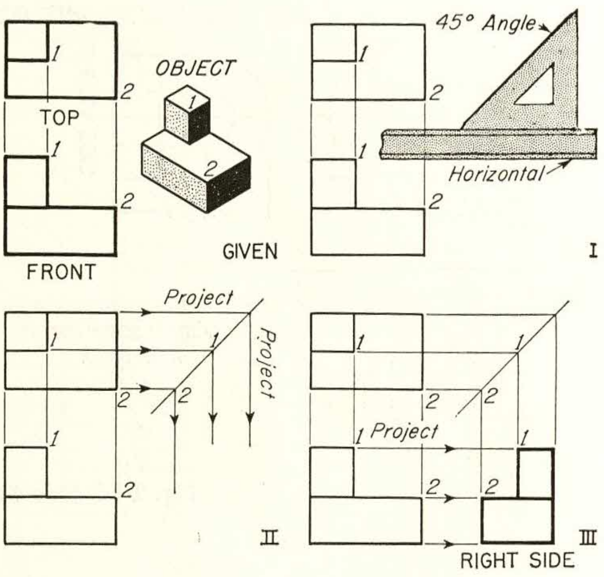


Fig. 2-12. Use of a miter line.

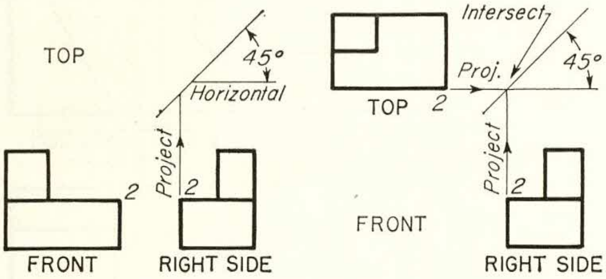


Fig. 2-13*a*. Miter line used for drawing the top view and for drawing the front view.

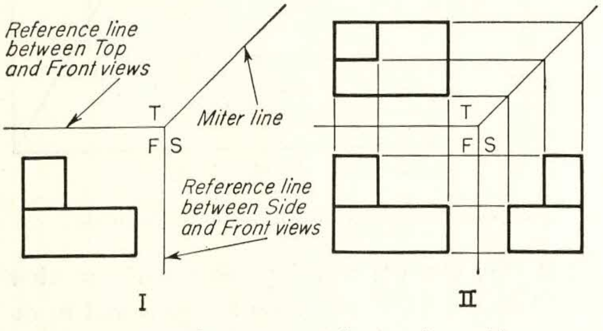

Reference line between Top and Front views
T
F S
Miter line
Reference line between Side and Front views
I
T
F S
II

Fig. 2-13*b*. Location of miter line with reference lines.

2-14. Alternate position for the side and rear views. If a three-view drawing is necessary for complete description of a part, it may be desirable to draw the side view in an alternate position to allow room at the lower right for the title block and notes. To permit this alternate arrangement, it should be imagined that the plane of projection of the right-side view is hinged to the top view rather than the front (see Fig. 2-14). Note that this means that the side view is turned 90° from what its position would be in the normal three-view arrangement; in effect, the side view is shown on its side. The same principles may be applied to draw a left-side view in an alternate position.

A rear view may be drawn in an alternate position also, in which case it is considered to be hinged to the top rather than to the left-side view (see

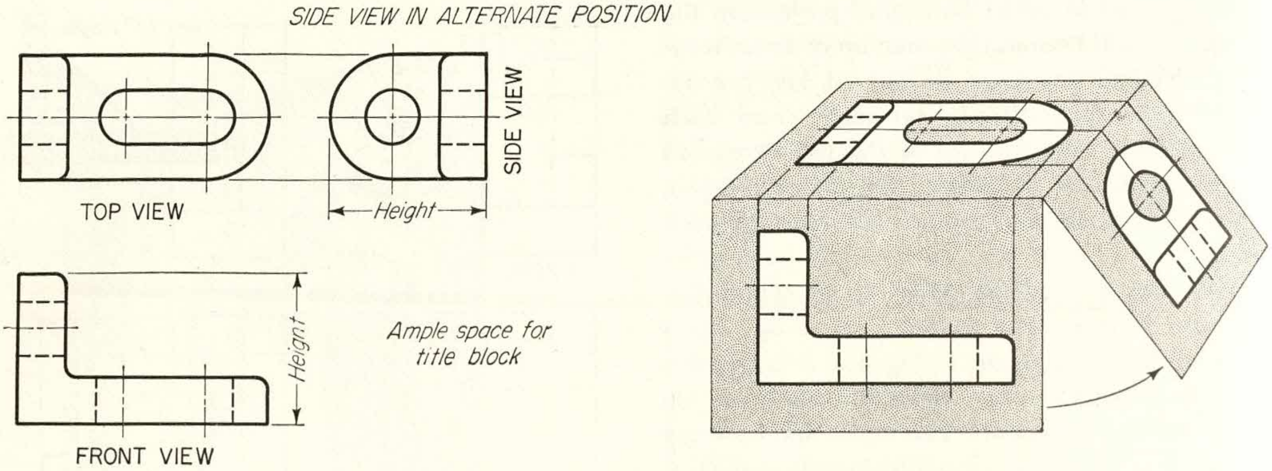


Fig. 2-14. Side view in alternate position.

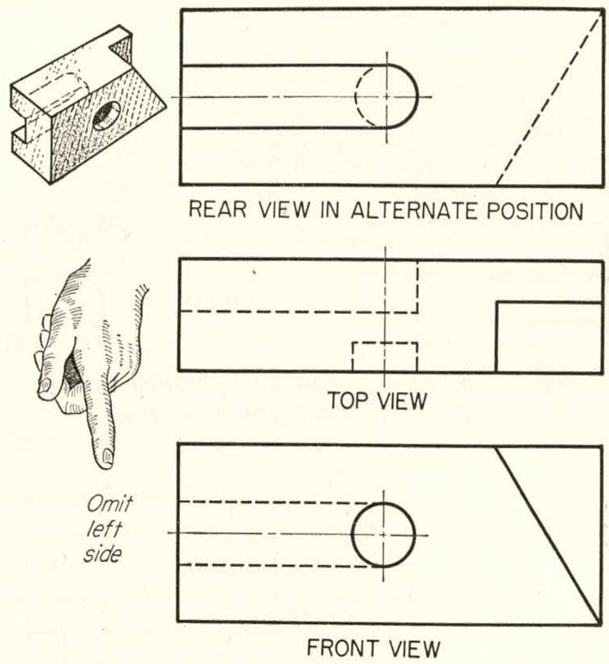


Fig. 2-15. Rear view in alternate position.

Fig. 2-15). On the drawing sheet the rear view would then appear above the top view and in direct projection from it. When the rear view is shown in this alternate position, the left-side view is not drawn on the same sheet.

2-15. Selection of views. The proper selection of views is of the utmost importance in orthographic drawing. In general, the draftsman should select the least number of views that will accurately describe the piece that is to be drawn and that will permit complete dimensioning. Unnecessary or poorly chosen views should be avoided, since they are confusing and waste valuable time in the shop. On the other hand, it is sometimes desirable to include a view that might technically be unnecessary in order to clarify a particularly intricate detail or to avoid a bewildering number of hidden lines in one of the other views. Proper selection of views is a skill that comes only with practice and with the development of the draftsman's ability to visualize the object on the drawing paper. Actual drawing experience and practice in reading drawings and blueprints will be of invaluable assistance to the beginning draftsman in developing skill and judgment.

Simple cylindrical pieces may be shown in a single view, the view that shows the axis as a center line (see the left portion of Fig. 2-16). This view is called a "profile," or "longitudinal," view. The diameters are dimensioned by an arrow-tipped leader that touches the part. The abbreviation D or DIA for diameter must always follow the dimension. When a cylindrical piece contains slots, holes, or other features that cannot easily be revealed in one view, additional views may be required (see the right side of Fig. 2-16).

A part that is symmetrical about either its main vertical or its main horizontal center line requires only two views. Careful analysis of the part will enable the draftsman to determine whether a side or a top view is called for after the front view has been selected (see Fig. 2-17).

Irregular objects generally require three prin-

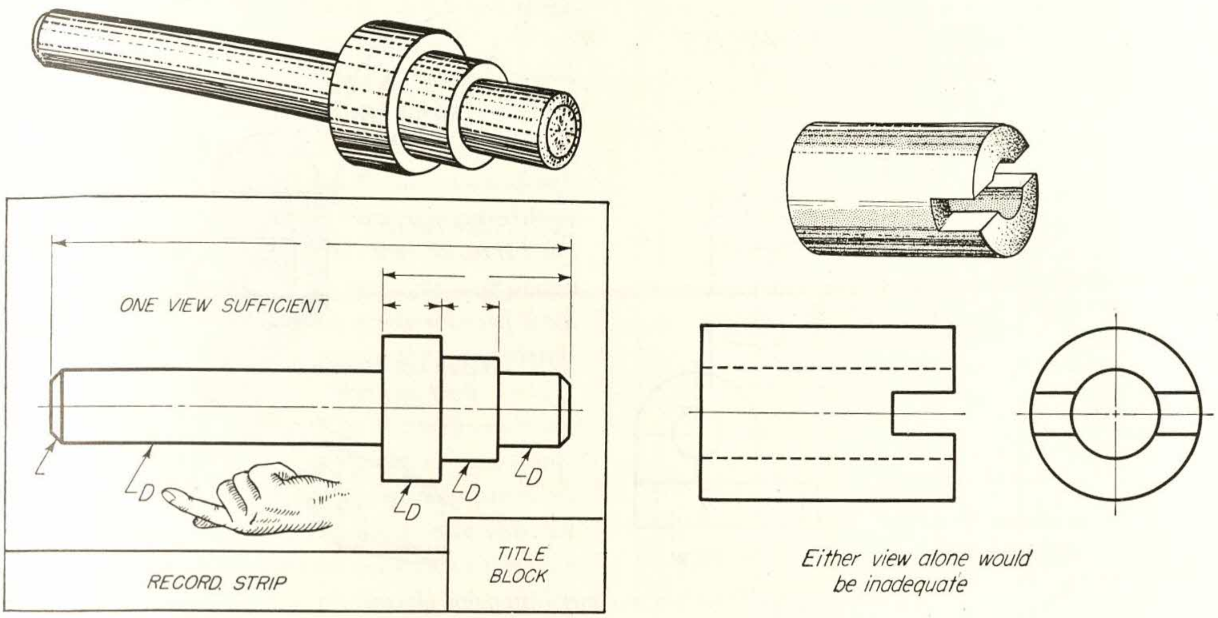


Fig. 2-16. Selection of views—cylindrical pieces.

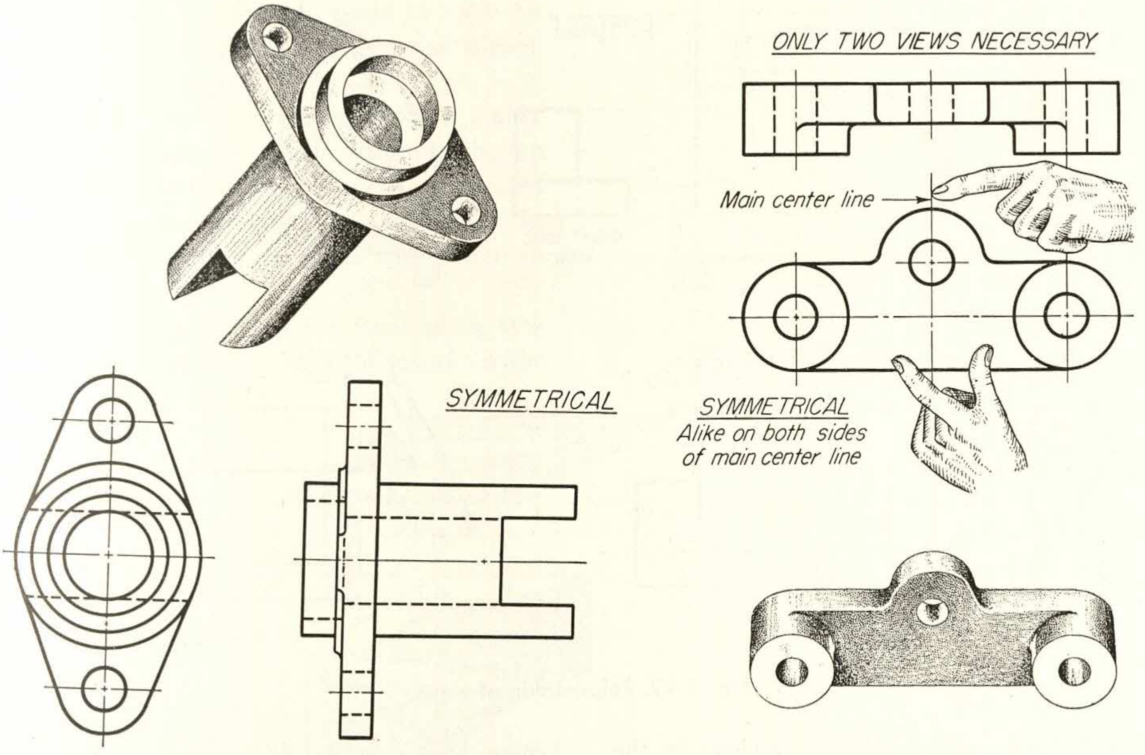


Fig. 2-17. Selection of views—symmetrical pieces.

cipal views for complete shape description and dimensioning. Note that the part shown in Fig. 2-18 cannot be represented clearly by any two-view combination. Three views are absolutely necessary to show the shape and features of the object. Some irregular or complicated objects may require more than the standard three views to describe them adequately. Sometimes what are known as "primary auxiliary" and "secondary auxiliary" views must be used to describe a piece properly. These views are discussed in detail in Chaps. 9 and 10.

Drawing views correctly and placing them in

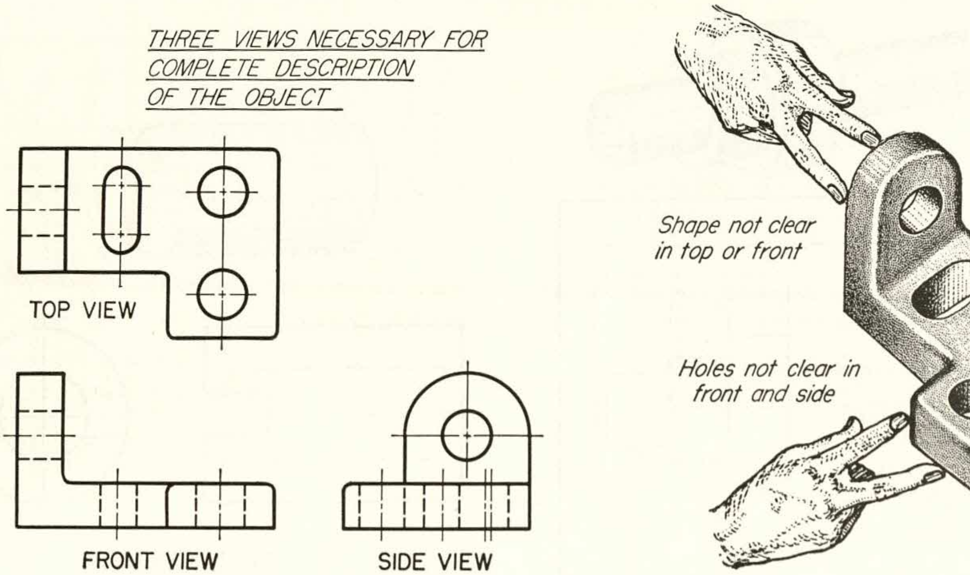

THREE VIEWS NECESSARY FOR COMPLETE DESCRIPTION OF THE OBJECT
TOP VIEW
FRONT VIEW
SIDE VIEW
Shape not clear in top or front
Holes not clear in front and side

Fig. 2-18. Selection of views—irregular pieces.

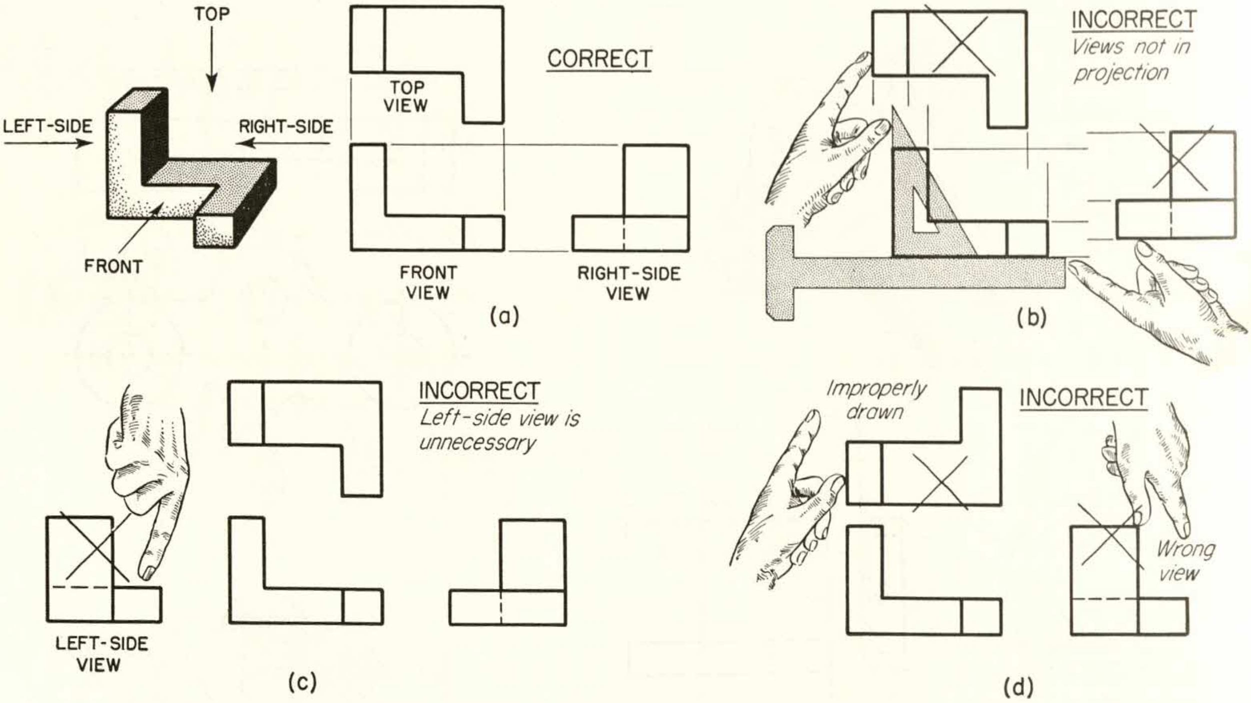


Fig. 2-19. Relationship of views.

proper relation to each of the other views on the drawing sheet make the entire drawing easy to read and understand. As an illustration of this principle, see Fig. 2-19. At (*a*), the positions of the three principal views—front, top, and right-side—are shown in their proper projected relationship. The representation at (*b*) is not acceptable, however, since the top and side views, though correctly drawn, are not placed in direct projection from the front view. At (*c*), the left-side view adds nothing of importance to the description of the piece, and therefore it should be rejected as unnecessary. The top and side views shown at (*d*) are incorrectly drawn. The top view is a mixture of top and bottom views, and the right-side view is really a projection of the left-side view. The views are said to be "out of projection," and therefore the whole drawing is unacceptable.

Figure 2-20 illustrates an unwise choice of views. The front view could have been taken from the other side of the object to avoid extra hidden lines, thus changing the appearance of the top and side views. Better still, the present side view could have been taken as it is for the front view. Then the top view would be rotated 90° to the right and placed in direct projection above this newly selected front view. These two views alone would then adequately describe the piece.

2-16. Analysis of lines. The draftsman should become thoroughly familiar with the appearance of the lines and planes of an object when projected to the image plane so that he can readily visualize which views will show the true lengths of the lines and the true shapes of the planes. A clear understanding of the principles of line and plane projection will help him to decide the probable number and types of views necessary to solve his immediate problem in representation and dimensioning (see Fig. 2-21).

A line that is parallel to the top plane is a horizontal line and is seen in its true length in the top view. Note from the figure that line 1-2 is parallel to the reference line (folding line) in the front view and therefore appears in its true length in the top view.

A line that is parallel to the front plane is a frontal line and is seen in its true length in the

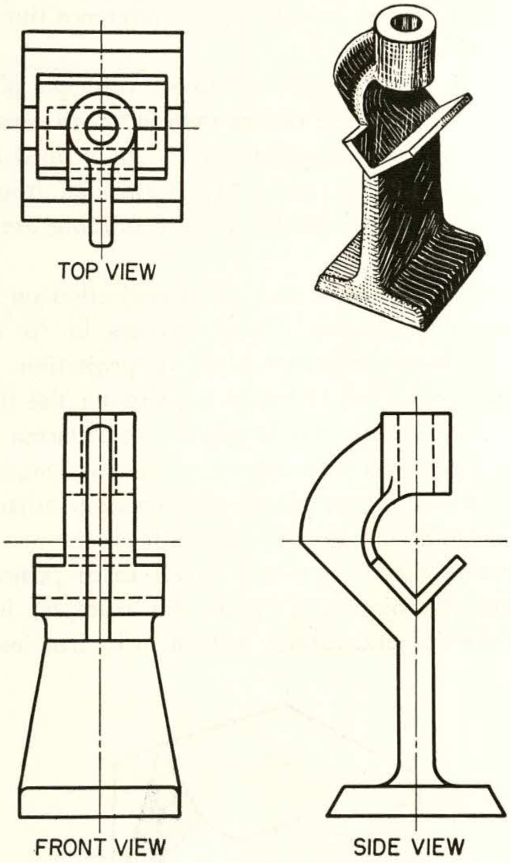


Fig. 2-20. Poor choice in selecting views.

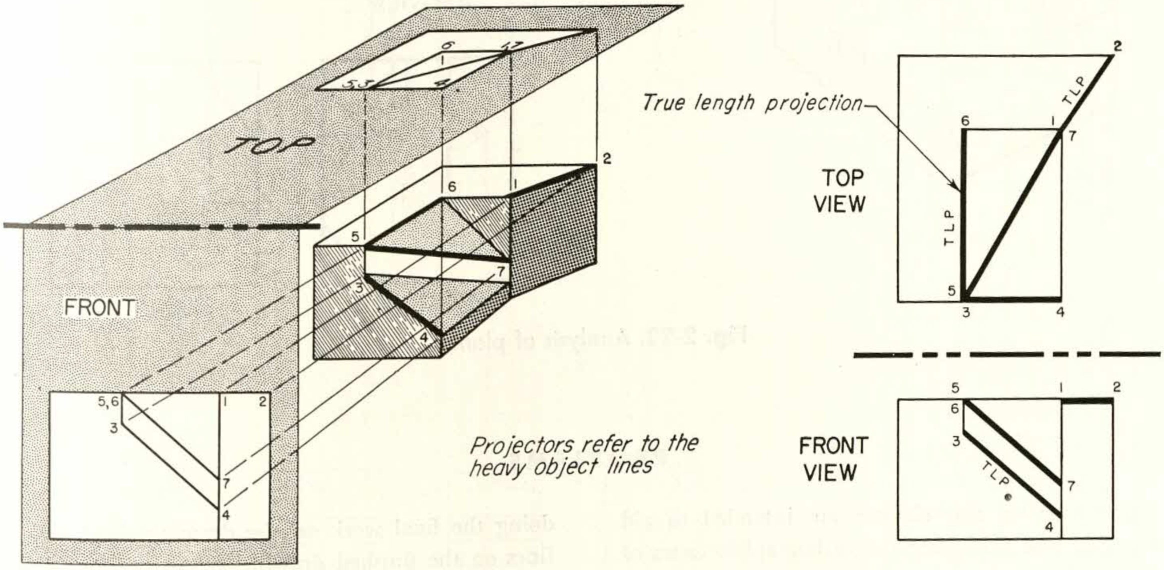


Fig. 2-21. Analysis of lines.

front view. Line 3-4 is parallel to the reference line in the top view and therefore appears in its true length in the front view.

A line that is parallel to the side planes is a profile line and is seen in its true length in either side view. It lies parallel to the reference line for either side view.

Any line that lies parallel to one principal plane and makes an angle of less than 90° with each of the other two principal planes is an inclined line (see lines 1-2, 3-4, and 6-7). Horizontal, frontal, and profile lines fulfilling these conditions are inclined lines.

A line that shows as a point projection on one plane of projection always appears in its true length on any adjacent plane of projection. For example, line 5-6 shows as a point on the front plane and in its true length in the adjacent top plane. It would also appear in its true length in the side and bottom planes, which are also adjacent to the front view. See also Sec. 15-14.

A line that is inclined to all three principal planes of projection (line 5-7, for example) is an *oblique* line and cannot be seen in its true length in any of the principal views. Such a line will be seen in its true length only in an auxiliary view, the principles of which are explained in the chapters on auxiliary views and descriptive geometry.

2-17. Analysis of planes. A plane appears in its true shape only when it lies parallel to the plane of projection. In Fig. 2-22, plane 1 is parallel to the front view and is seen in its true shape in that view, plane 2 is parallel to the top view and is seen in its true shape in that view, and plane 3 is parallel to the side view and will be seen in its true shape in either side view. Planes 4, 5, and 6, however, are each perpendicular to one of the principal planes and inclined to the other two. These are called *inclined planes,* and their true shapes can be seen only in primary auxiliary views. Plane 7 lies oblique to all three principal planes of projection and is called an *oblique plane.* The true shape of this plane can be shown only in a secondary auxiliary view. The manner in which the true shapes of inclined and oblique planes can be represented is explained in the chapters on primary and secondary auxiliaries and on descriptive geometry.

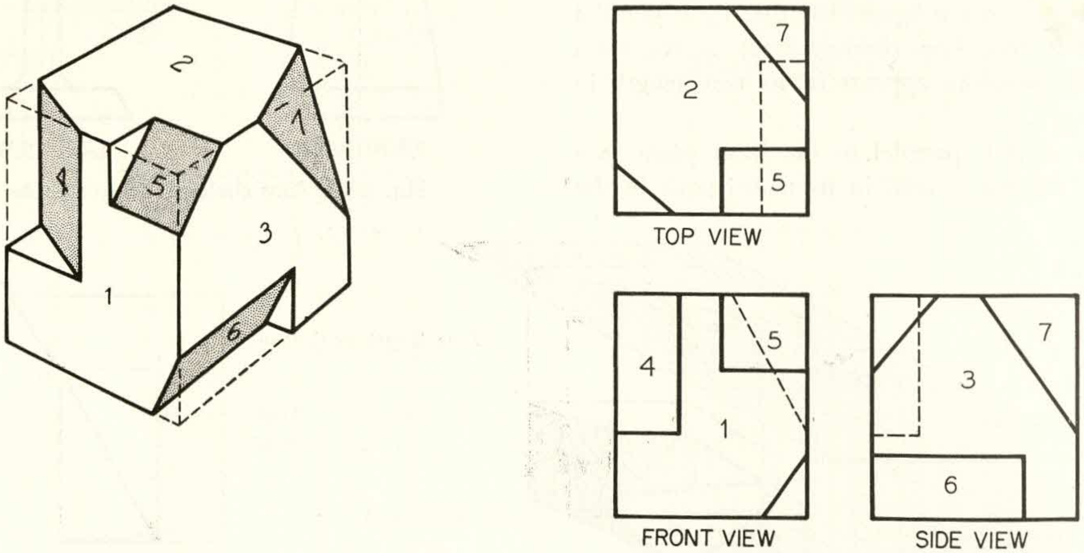


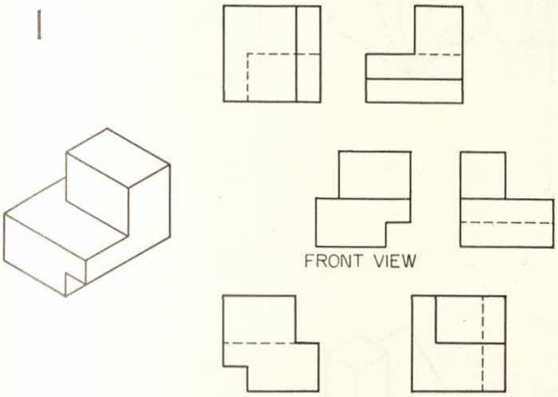
Fig. 2-22. Analysis of planes.

PROBLEMS

The problems for this chapter are intended to aid in visualizing and arranging the orthographic views of an object and as an introduction to freehand sketching. Preliminary layout sketches should be made before doing the final work on the drawing sheet. All pencil lines on the finished drawing are to be done lightly at first and made heavy only after they have been accurately interpreted. The drawings are not to be dimensioned, although they should be reasonably proportionate to the views shown in the text. They may be enlarged where suggested for each group of problems. It is recommended that the drawing sheet be a standard size, such as 8½ by 11 in. or 11 by 17 in. If cross-section paper is available, it should be used, for it will aid in developing a sense of proportion and dimensioning and in aligning the views in relation to each other.

Group 1. Problems 2-1 to 2-5. Use an 8½- by 11-in. drawing sheet for each problem. Place a ½-in. border all around. Sketch the pictorial in the upper right corner of the sheet. Place the front view in the area it should occupy on the sheet. Then select among the other given views the top, left-side, right-side, bottom, and rear views and place them in their proper positions in relation to the front view. The views should be drawn approximately twice the size shown.

1



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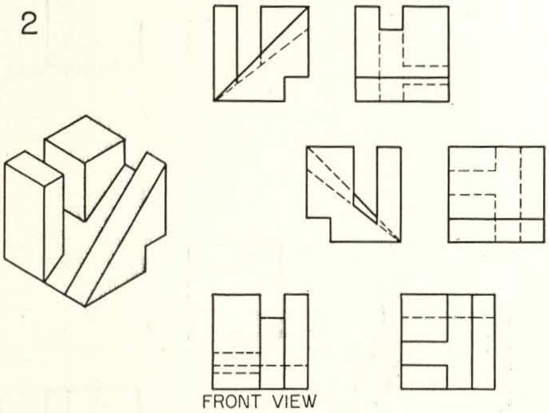

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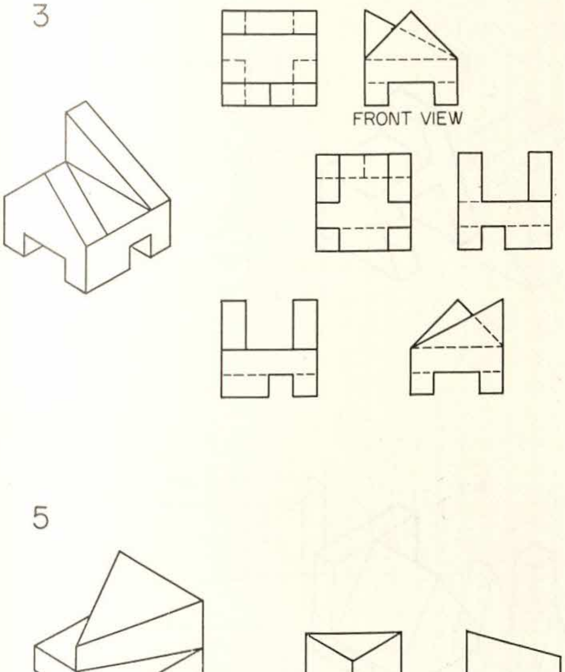

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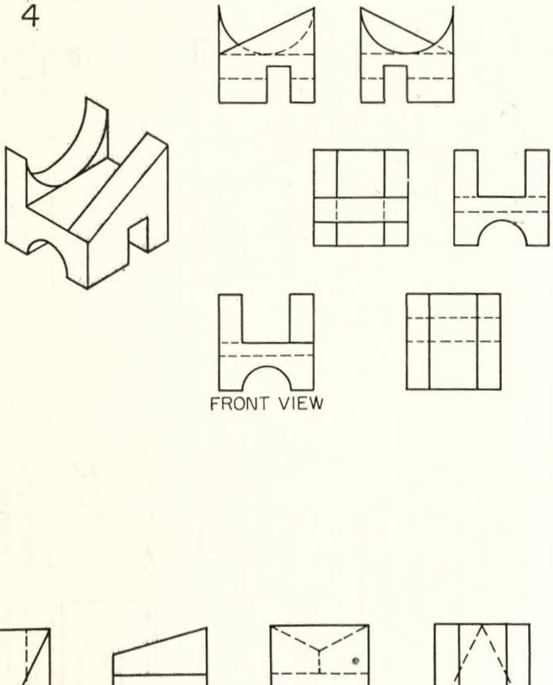

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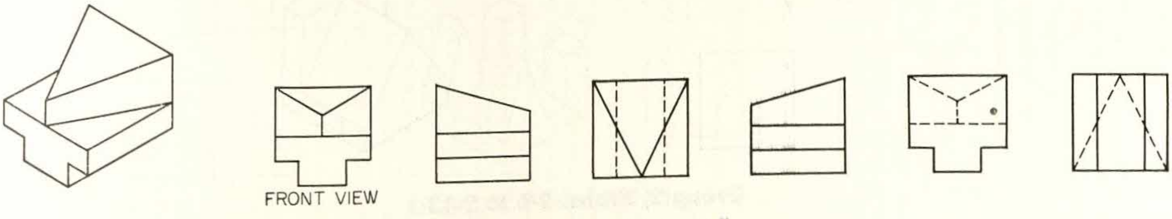
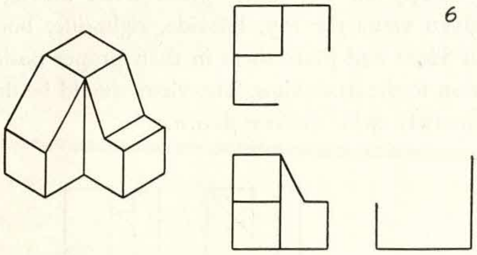


Group 1, Probs. 2-1 to 2-5.

Group 2. Problems 2-6 to 2-13. These problems should be drawn approximately three times as large as they appear in the text. Sketch the pictorial in the upper right corner of the sheet. Place the completed front view in the space it would normally occupy on the sheet. Complete the top and right-side views, and add a left-side view.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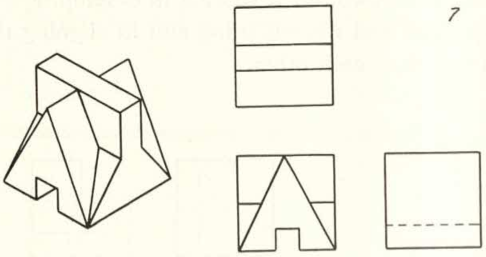
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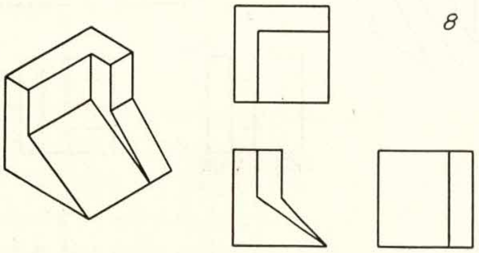
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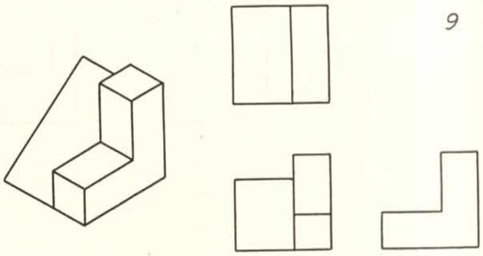
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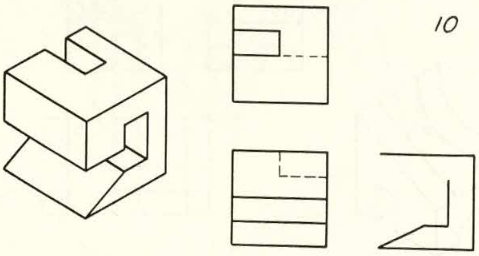
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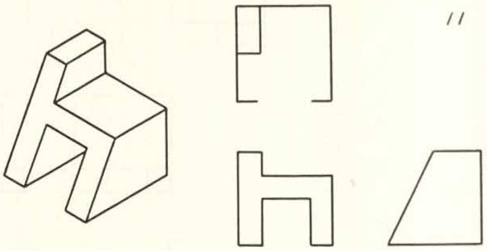
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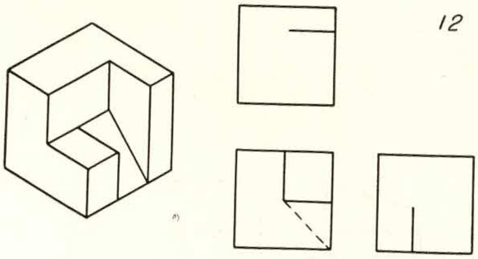
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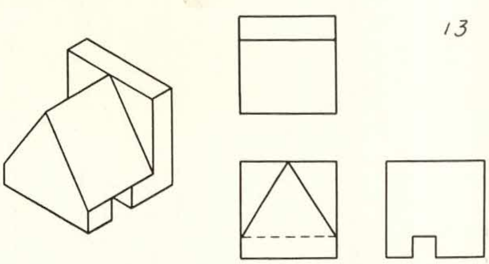
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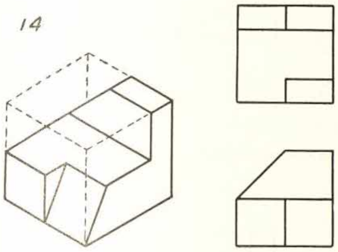
Group 2, Probs. 2-6 to 2-13.

Group 3. Problems 2-14 to 2-25. The views are to be shown about three times the size they appear in the text. Sketch the pictorial at the upper right of the sheet, omitting the dotted lines. Draw the given front and top views, and add left- and right-side views. Check all four of the orthographics to see whether or not they satisfy the structural requirements of your interpretation of the pictorial.

14



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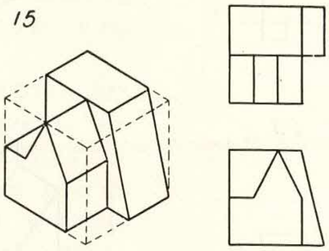

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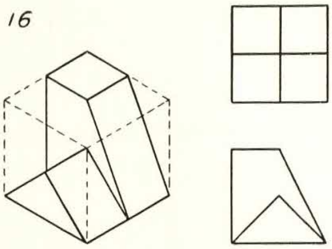

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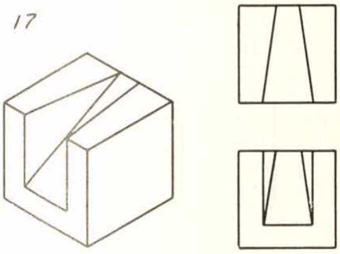

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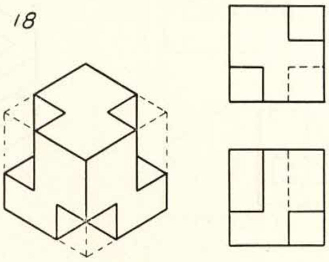

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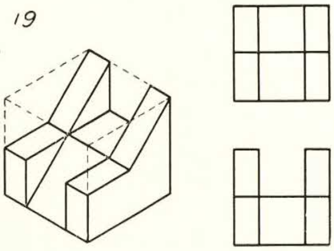

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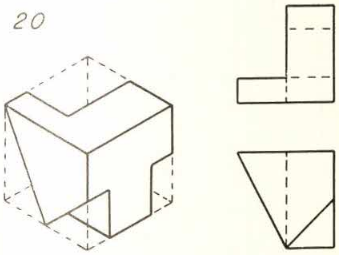

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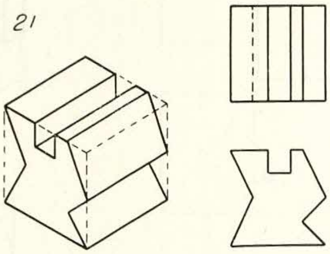

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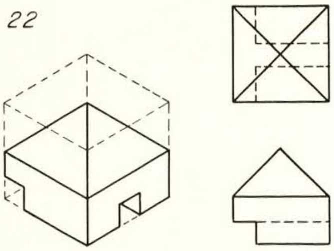

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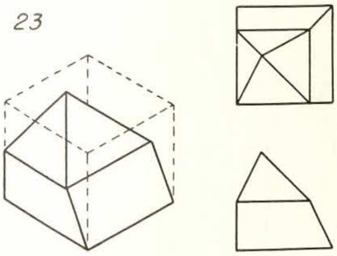

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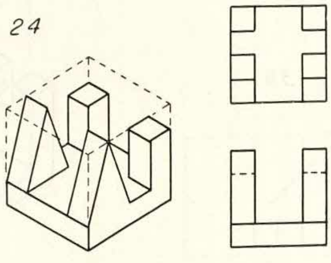

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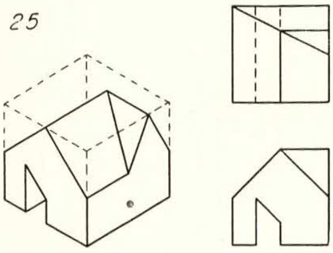

Group 3, Probs. 2-14 to 2-25.

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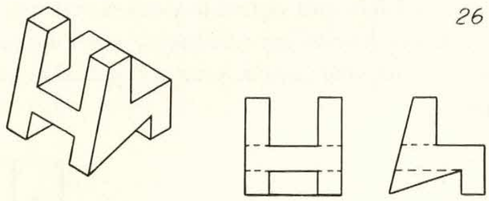

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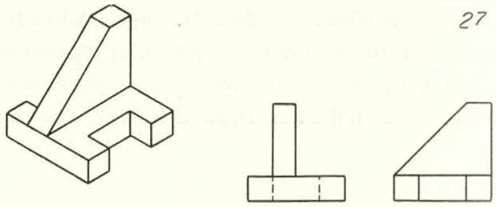

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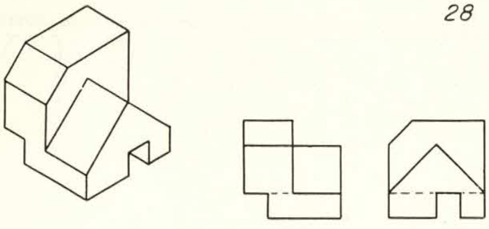

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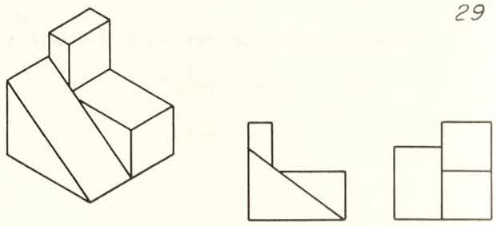

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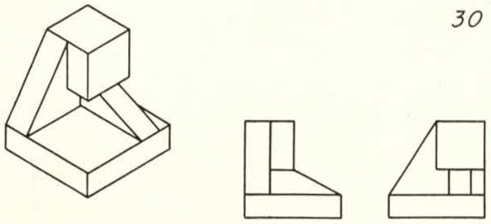

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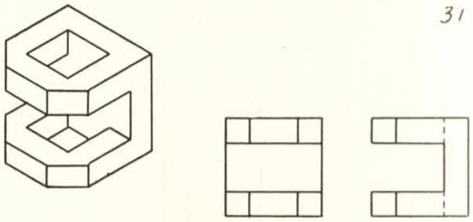

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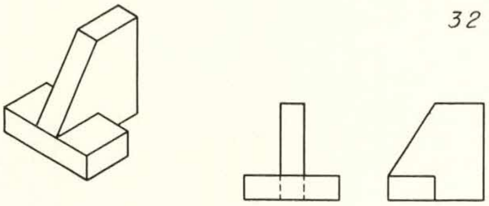

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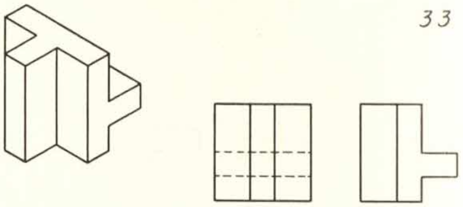

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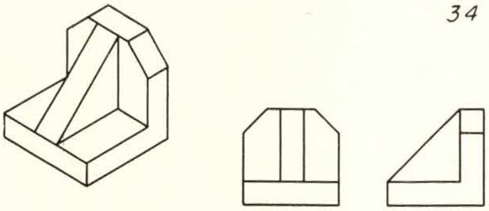

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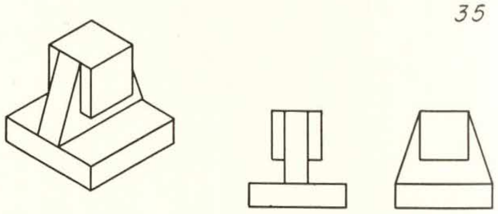

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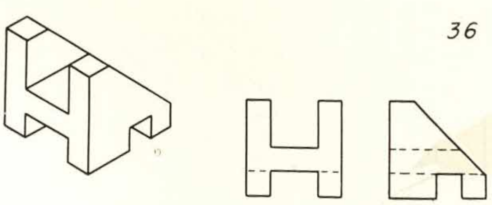

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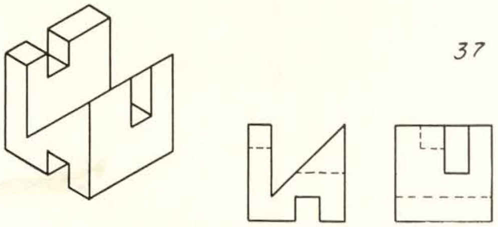


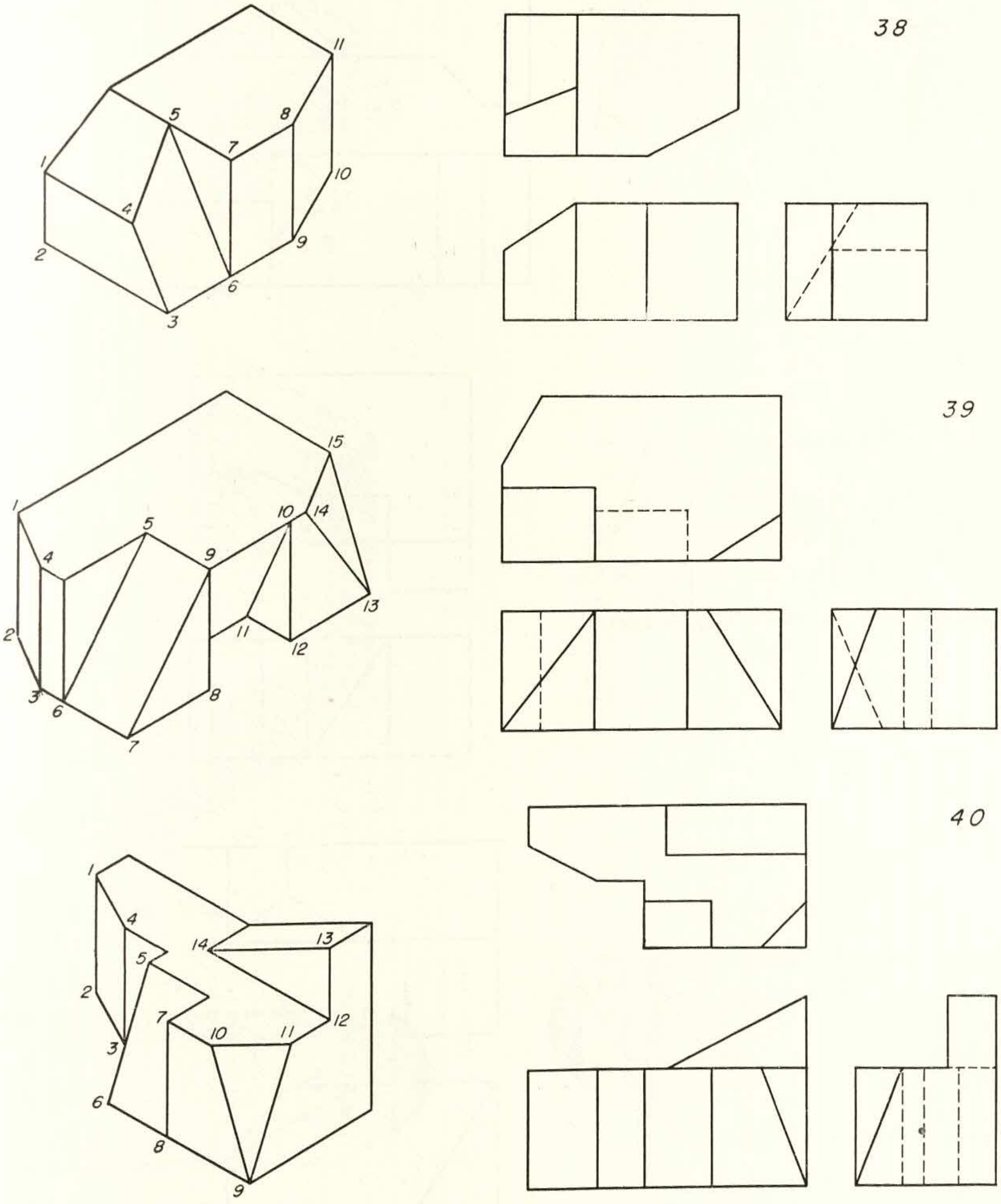
Group 4, Probs. 2-26 to 2-37.

Group 4. Problems 2-26 to 2-37. The views should be shown about three times the size they appear in the text. Sketch the pictorial at the upper right of the sheet. Add top and left-side views. Check the accuracy of the orthographics to see whether or not they satisfy the structural requirements of your interpretation of the pictorial.

Group 5. Interpretation of lines. Problems 2-38 to 2-40. Redraw the three given views about twice the size shown in the text, and number the lines as shown on the pictorial. Leave enough room at the right above the side view to reproduce the chart illustrated. In the first column, list each numbered line. In the next columns, specify whether the line is a true-length projection, a point projection, or inclined or oblique to the view shown at the top of the column.

Line	In front view	In top view	In side view
1-4	Point proj.	True length	True length
3-4	Inclined	Inclined	True length

(The two lines above appear in Prob. 2-38.)

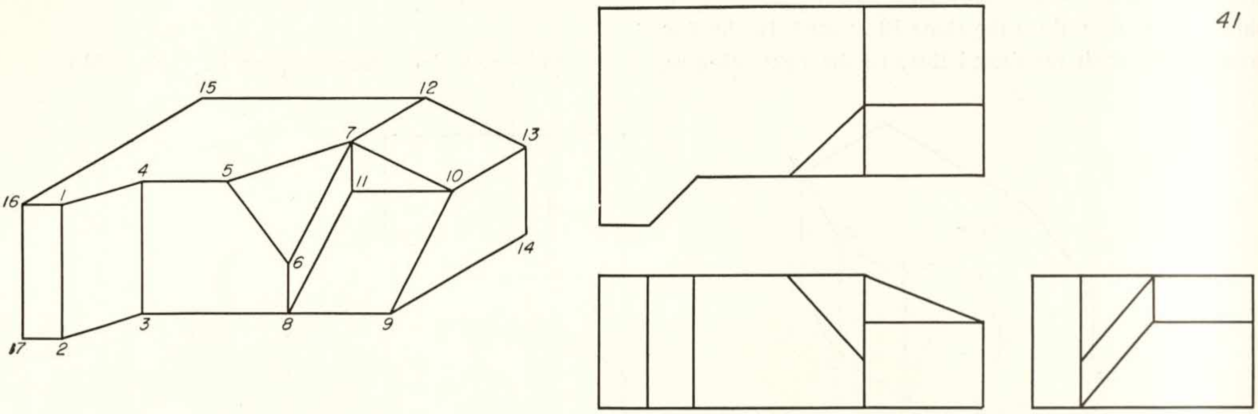


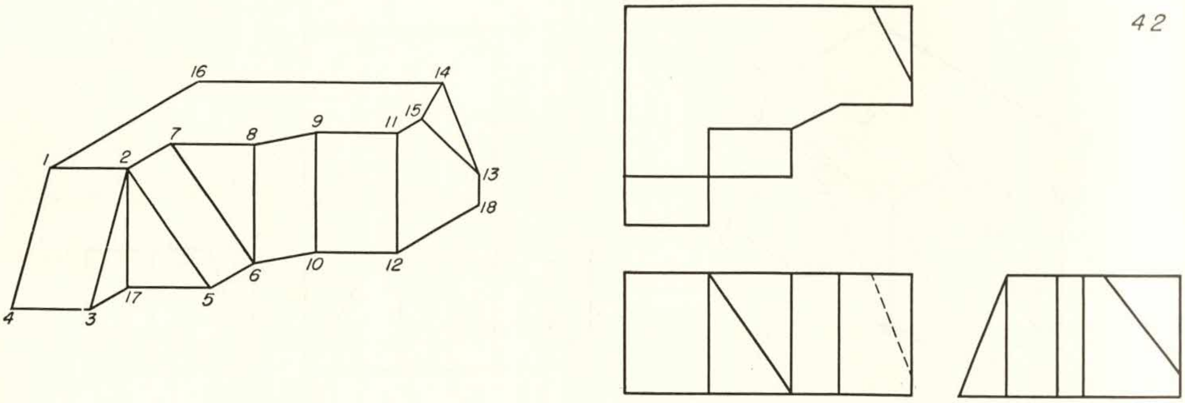
Group 5, Probs. 2-38 to 2-40.

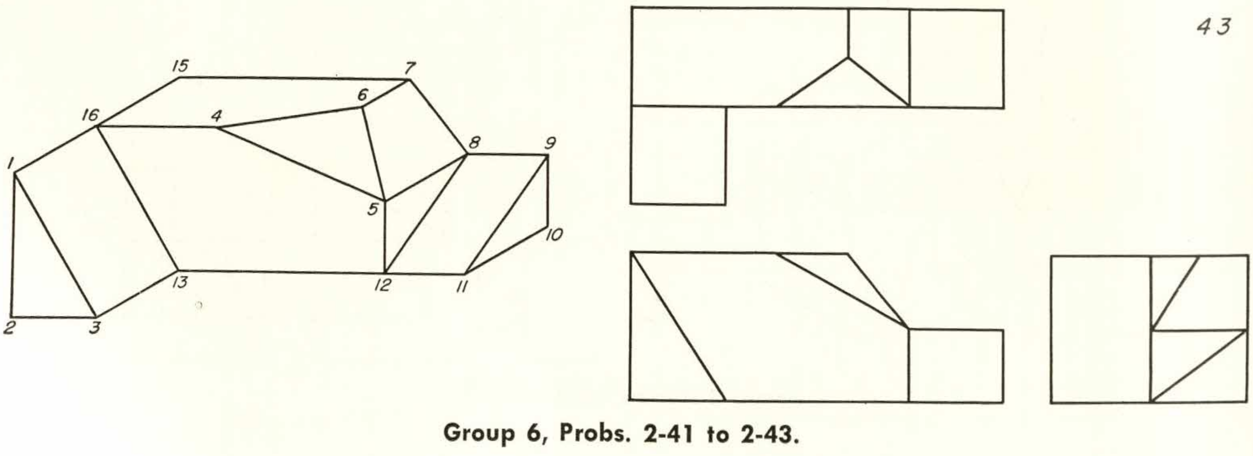
Group 6. Interpretation of planes. Problems 2-41 to 2-43. Sketch the given orthographics about twice the size shown. Number the planes as they appear in the pictorial. At the right and above the side view, reproduce the chart illustrated. List each plane in the left-hand column, and at the right indicate whether it appears in its true shape, as an edge, or inclined or oblique to the front, top, and right-side views.

Plane	In front view	In top view	In side view
1-2-3-4	Inclined	Edge	Inclined
5-6-7	Oblique	Oblique	Oblique

(The two planes analyzed above appear in Prob. 2-41.)

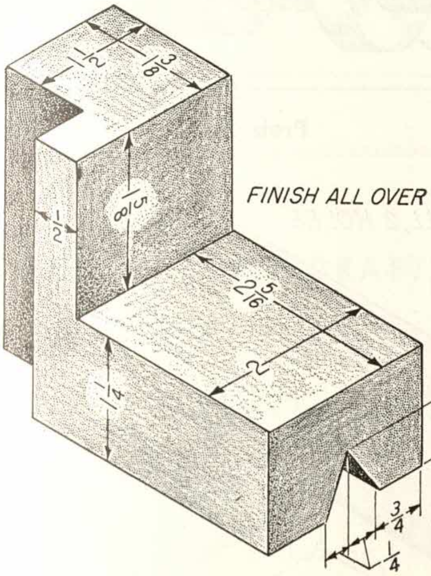




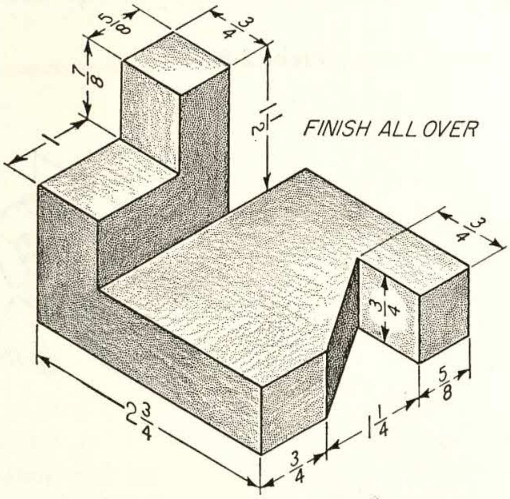


Group 6, Probs. 2-41 to 2-43.

Group 7. Problems 2-44 to 2-54. To give the student training in pictorial visualization and sketching to accurate scale, the problems in this group are presented as full-tone dimensioned pictorials. Analyze the object carefully; then sketch the minimum number of orthographic views, in proper relation to each other, to describe the object adequately. Drawings should be made on an 8½- by 11-in. sheet.



Prob. 2-44.



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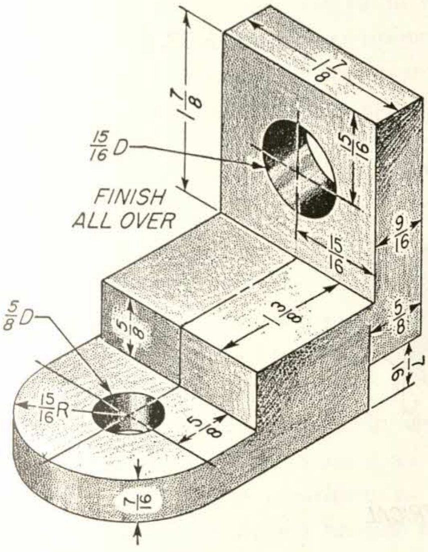

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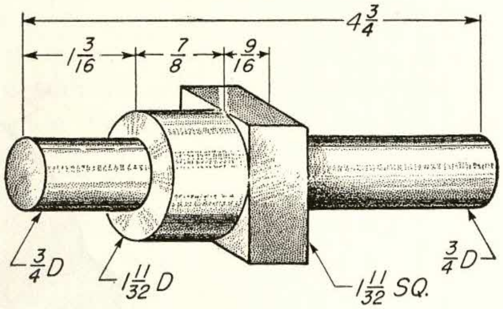
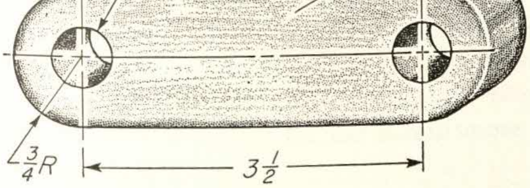
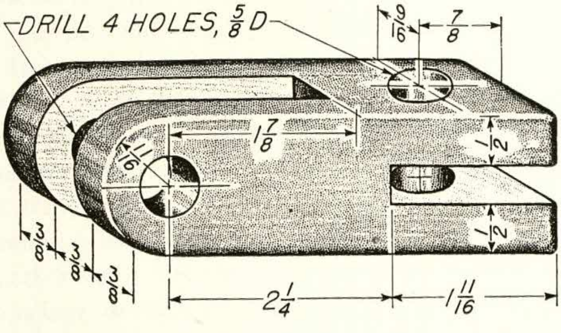


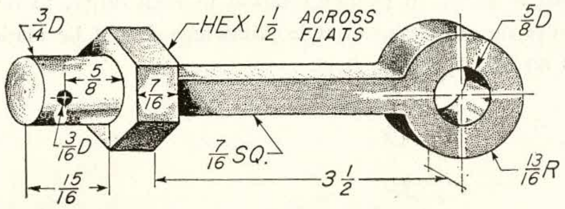
Prob. 2-47.



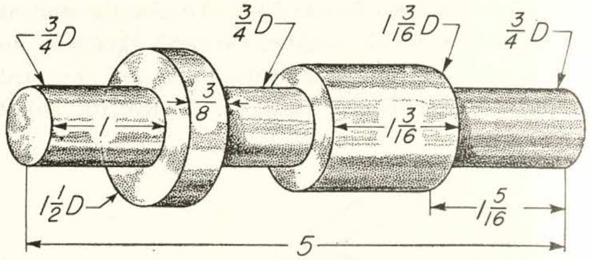
Prob. 2-48.



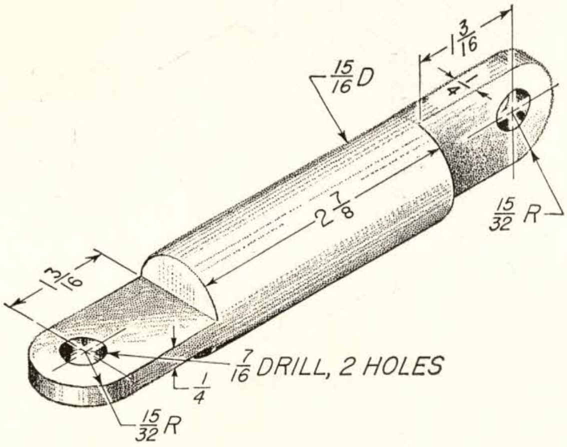
Prob. 2-49.



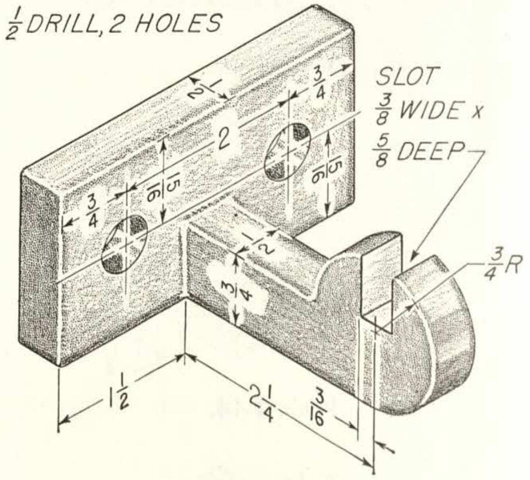
Prob. 2-50.



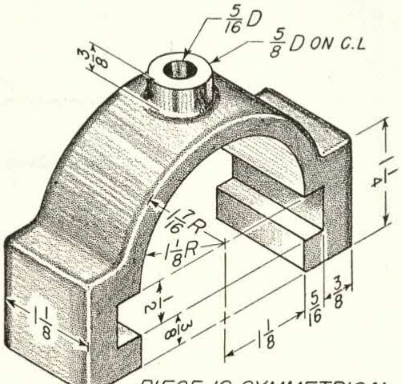
Prob. 2-51.



Prob. 2-52.



Prob. 2-53.



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Prob. 2-54.

Chapter 3

FREEHAND DETAIL DRAFTING

The practicing engineer seldom has his instruments available when the necessity arises for producing a working sketch or drawing for an idea that may come suddenly to his mind. Also, he may occasionally come upon some piece of equipment that needs repair and will be obliged to make a sketch while lacking his complete complement of drawing tools. However, every engineer can find a sheet of paper, a pencil, and an eraser available, no matter what the working conditions may be. With these, if he has been properly trained in the fundamentals of sketching, he can produce a drawing from which the draftsman or designer can prepare a complete instrumental representation.

Industry considers freehand-drawing ability to be a valuable accomplishment. The basic concepts of orthographic projection and drawing procedure are more easily grasped when started by freehand methods. Once you are able to produce an acceptable freehand drawing, the transition to instrument work is easily accomplished because of your acquaintance with the fundamental procedures and techniques. Even more important will be a feeling for the work and a true understanding of what you are trying to accomplish.

3-1. The detail drawing. A detail drawing is an orthographic representation of a single part which shows all the necessary views, dimensions, and notes including the title-block and record-strip information required for the manufacture or fabrication of the part.

In a large manufacturing plant with many departments or divisions, separate detail drawings that show only the specific operations required in each division are usually prepared. For example, a pattern detail is prepared for the pattern shop, a foundry detail is prepared for the foundry shop, a machining detail is prepared for the machine shop, etc. All these detail drawings are worked up from the designer's detail sketches by the designers and draftsmen in the drawing department. Small plants with limited facilities, on the other hand, encourage their draftsmen to prepare general-purpose detail drawings that will permit any worker to perform his required task. All the necessary notes and dimensions are shown on the one drawing, thus enabling any type of worker—the patternmaker, the foundry man, the machinist, etc.—to work from a single sheet. A large part is shown alone on the sheet. If a number of small parts can be represented clearly and completely, grouped in good composition at a suitable scale, several of them may be shown on a single sheet if they bear an assembly relationship to each other.

In order to develop all-round ability, the student should concentrate on the preparation of general-purpose drawings. However, he should also become familiar with the particular requirements of drawings that go into individual departments or divisions, for he may be confronted at one time or another with the task of producing specialized drawings for the various shops.

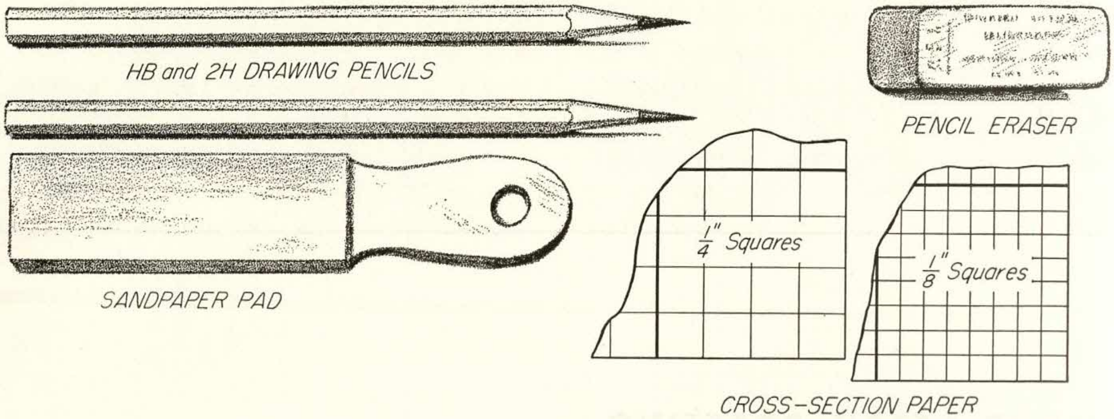


Fig. 3-1. Freehand drafting tools.

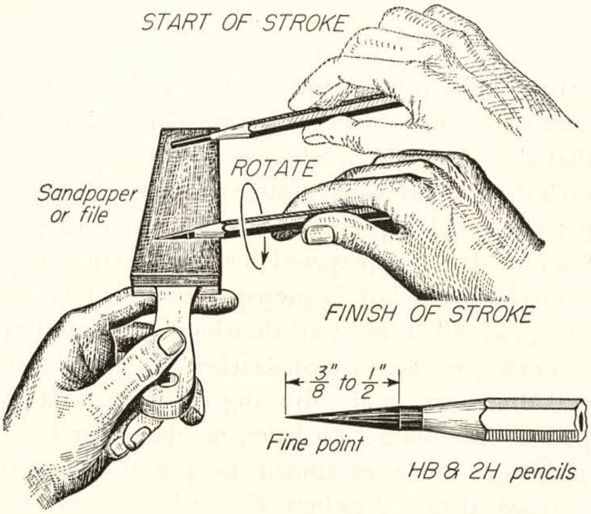


Fig. 3-2. Sharpening the pencil.

3-2. Freehand drafting tools. The tools required for freehand drawing are illustrated in Fig. 3-1. Two pencils are desirable—a 2H for preliminary sketching and an HB for darkening the lines. In addition, the draftsman will need a sandpaper pad to keep the pencils sharpened, a soft pencil eraser to remove undesirable lines and clean up the paper from time to time, and a pad of 8½- by 11-in. cross-section or rectangular-coordinate paper. The cross-section paper is divided up into ⅛- or ¼-in. squares with the inch line accented. These divisions will keep the drawing at a reasonably accurate scale and will aid in producing straight lines.

3-3. Sharpening the pencil. To sharpen the pencil, first remove the wood from around the lead by use of a mechanical sharpener or a penknife. The exposed lead should then be sharpened to a conical point by rotating the pencil in contact with

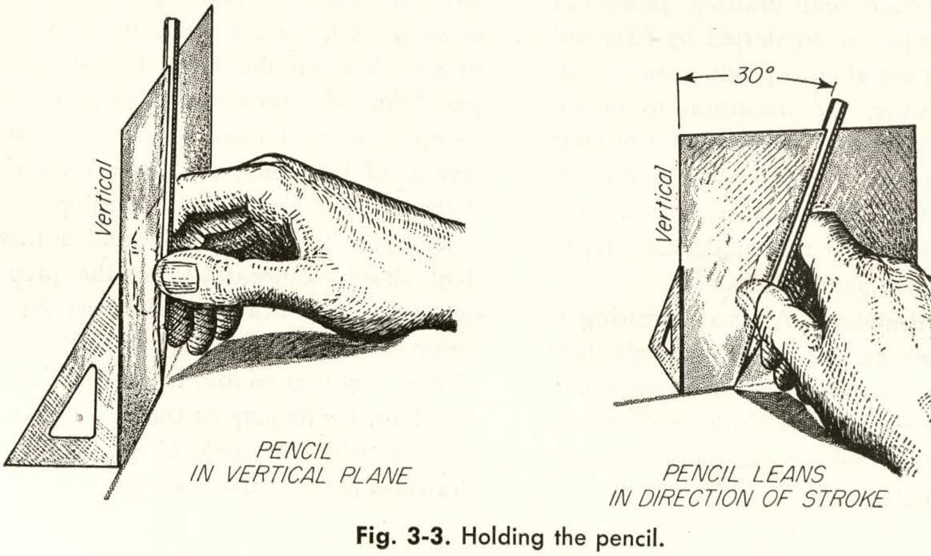


Fig. 3-3. Holding the pencil.

a sandpaper pad or fine file (see Fig. 3-2). The undesirable needle point can be dulled by sliding it across a piece of scrap paper several times.

3-4. Holding the pencil. The pencil should be held gently in a fairly vertical plane and should be inclined approximately 30° in the direction of the stroke that is to be drawn (see Fig. 3-3). The thumb and forefinger should grip the pencil far enough away from the point to permit seeing the extreme point in all the various positions the hand may take while drawing (see Fig. 3-5).

3-5. Sketching straight lines. The easiest way to sketch a straight line is to swing the stroke in a horizontal direction from left to right. First mark the extremities of the desired line with light but distinct dots (if the line is long, intermediary dots should be used). Then hold the pencil about $\frac{1}{4}$ in. above the paper, and swing the hand through the

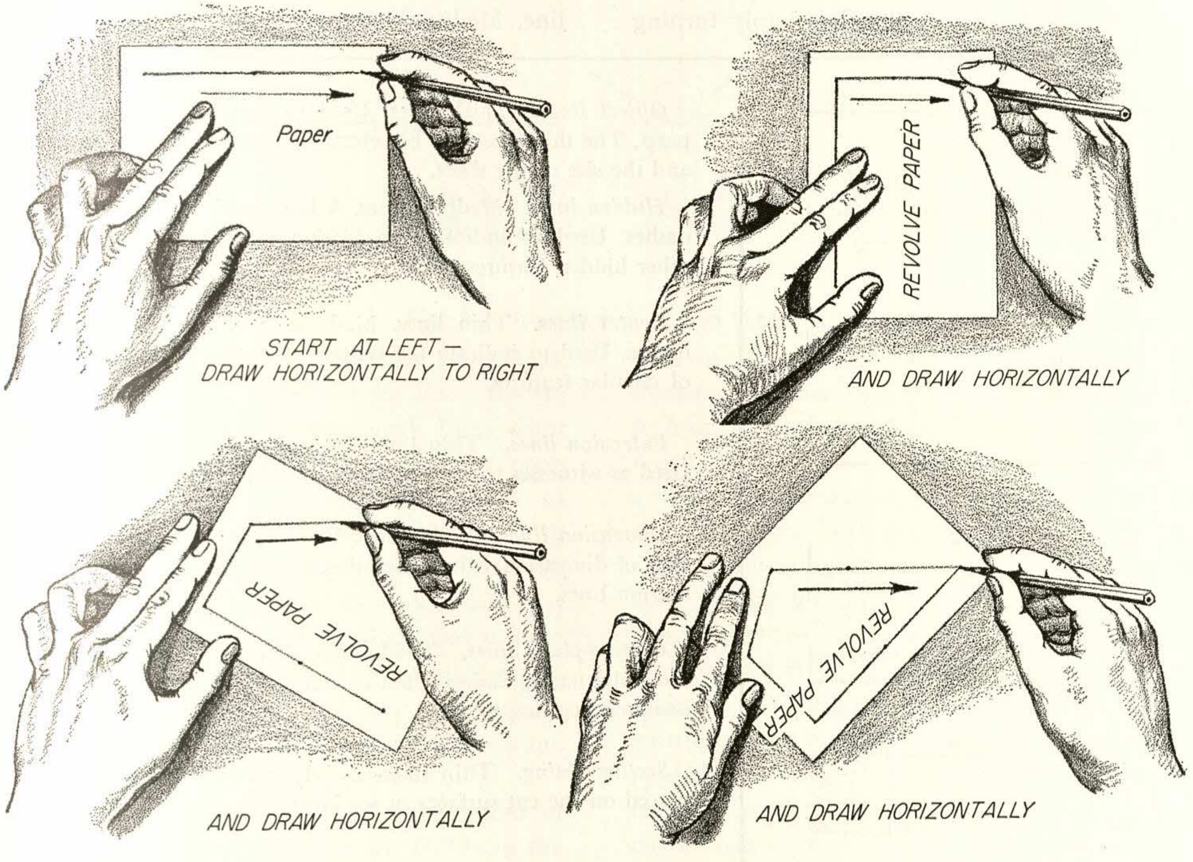


Fig. 3-4. Drawing all straight lines as horizontals.

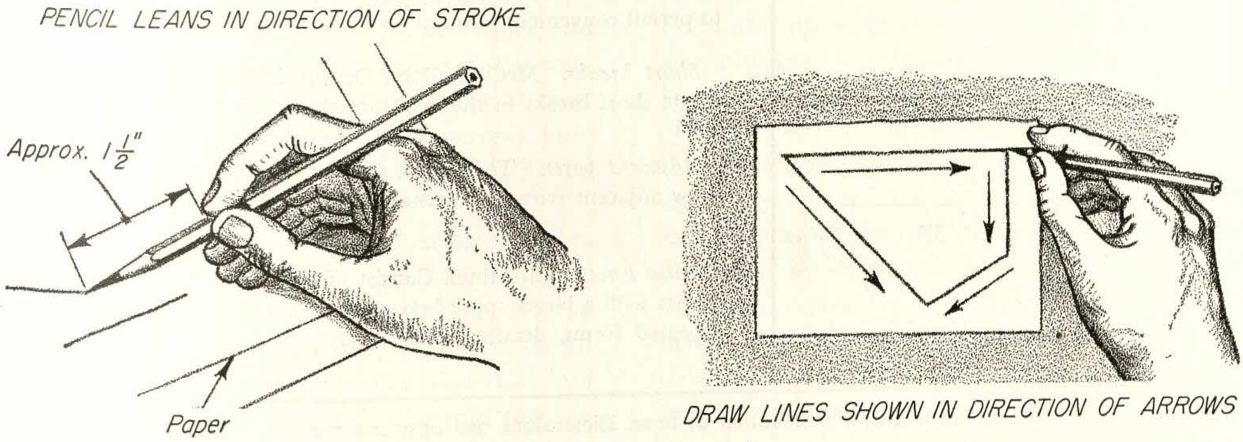
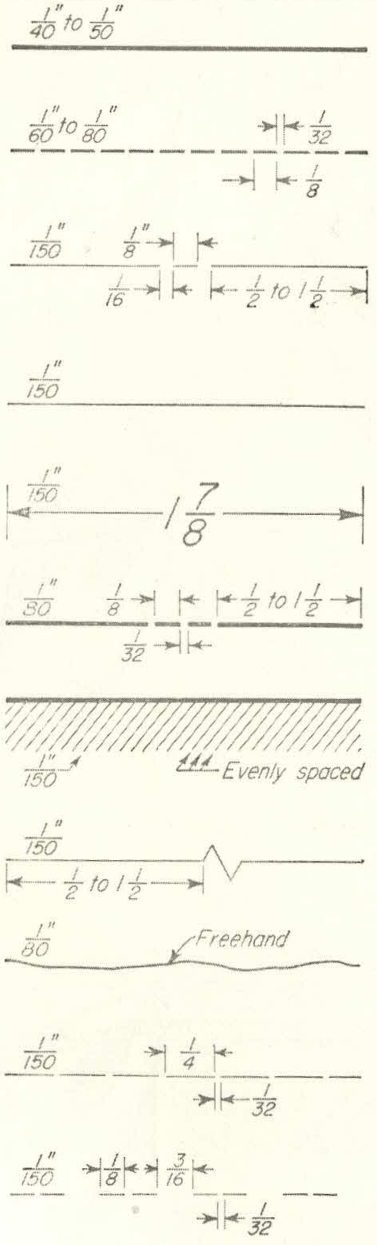

PENCIL LEANS IN DIRECTION OF STROKE
Approx. $1\frac{1}{2}''$
Paper
DRAW LINES SHOWN IN DIRECTION OF ARROWS

Fig. 3-5. Drawing straight lines.

path of the desired line from one dot to the other. After practicing this movement several times, touch the pencil lightly to the paper, and swing in the desired line. Short scraggly dashed lines should be avoided. If the first line drawn is not satisfactory, erase it and try again. When this light practice line approaches perfection, it may be darkened to the desired uniformity, intensity, and straightness.

Figure 3-4 illustrates how all straight lines, whether vertical, horizontal, or inclined, may be drawn with horizontal strokes by simply turning the drawing sheet. The experienced draftsman may draw short vertical and inclined lines in the direction of the arrows shown in Fig. 3-5, but a beginner is likely to have difficulty producing the inclined lines without considerable practice.

3-6. Classification of lines. In most engineering drawings, three *widths* of line of the same "blackness," or intensity, are called for: thick, medium, and thin. Thick lines are used for the visible outline of the object and the cutting-plane line. Medium lines are used for the hidden lines



Object lines. Thick lines. Used to show the visible outline of parts. The thickness may be selected to suit the size of the drawing and the size of the sheet.

Hidden lines. Medium lines. A line consisting of equally spaced dashes. Used to indicate the hidden intersections of planes and other hidden features of the object.

Center lines. Thin lines. Made with alternate long and short dashes. Used to indicate the centers of entire objects and locations of circular features.

Extension lines. Thin lines. Unbroken in their required length. Used as witnesses to the points on the object to be dimensioned.

Dimension lines. Thin lines. Unbroken except to permit insertion of dimension figure. Terminate in arrowheads that touch extension lines.

Cutting-plane lines. Thick lines. Consist of one long and two short alternating dashes. Used in sectioning to show the path of the imaginary cutting plane.

Section lining. Thin lines. Evenly spaced slant lines which are placed on the cut surfaces in section views.

Long breaks. Thin lines. Drawn with a straightedge and a freehand zigzag. These lines indicate that the structure has been broken to permit convenient location on the drawing sheet.

Short breaks. Medium lines. Drawn freehand and used to indicate short breaks in the structure shown on the sheet.

Adjacent parts. Thin lines. Consist of long dashes and used to show adjacent parts or alternate positions for the parts.

Ditto lines. Thin lines. Consist of alternate small-spaced double dashes with a larger space between them. They are used to indicate repeated forms, details, or features.

Fig. 3-6. Classification of lines. Dimensions are approximate.

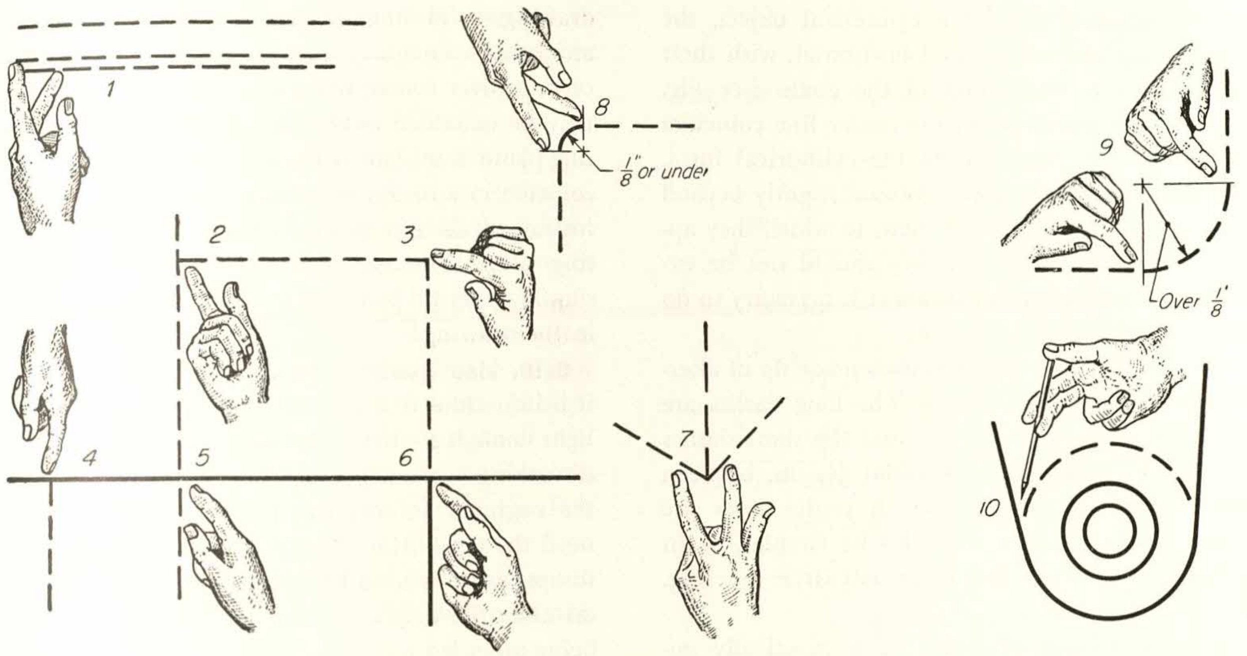


Fig. 3-7. Treatment of hidden lines.

representing hidden features and for short-break and alternate-position lines. Center lines, dimension lines, adjacent parts, long-break lines, ditto lines, extension lines, and section lining are represented by thin lines. A complete classification of these lines and their relative widths is shown in Fig. 3-6. Although these distinctions embody the ASA-preferred style, the Association does add that for "rapid practice" this may be simplified to two: "*medium* lines for outline, hidden, cutting-plane, short-break, adjacent-part, and alternate-position lines, and *thin* lines for section, center, extension, dimension, long-break, and ditto lines."

3-7. Hidden lines. Features or intersections of the planes of an object that are not visible in the direction from which a view is taken are shown in the drawing by the use of dashed lines. These lines are called hidden lines, or invisible lines, and as a general rule they should be shown unless coincident with solid object lines. In exceptional cases, hidden lines may be omitted if they are overabundant and tend to confuse rather than to clarify the representation.

A hidden line is formed by a series of dashes about $\frac{1}{8}$ in. long separated by spaces of about $\frac{1}{32}$ in. If hidden lines appear close together on the drawing, the dashes should be staggered as shown at 1 in Fig. 3-7. When one hidden line runs into another, the last dash of one line should touch a dash of the other, as shown at 2. Hidden lines forming a corner should touch as indicated at 3. A hidden line ending at a solid boundary line touches it as seen at 4. When a hidden line crosses a solid line, clearances may be left as illustrated at 5. A hidden line that is the continuance of a solid line begins with a space, or break, as shown at 6. Where several hidden lines show a hidden corner, they are treated as seen at 7. If the radius of a hidden arc is $\frac{1}{8}$ in. or less, the proper treatment is shown at 8, while 9 shows the method of representing hidden arcs with radii over $\frac{1}{8}$ in. The rules applying to straight lines are followed in the treatment of hidden circles, circle arcs, and irregular curves, one example being shown at 10.

3-8. Center lines. Generally speaking, center lines are drawn to indicate the axes of cylindrical forms and the main vertical and horizontal axes of an entire part. In drawing cylindrical forms or objects containing cylindrical features (such as shafts or holes), center lines are the first lines placed on the drawing sheet, since they establish the common axes of symmetry for such features in all views. In this way, center lines are of great assistance to the draftsman in laying out his drawing. Figure 3-8 illustrates typical uses of center lines. Although main center lines may be omitted if they are not required for clarity or dimensioning, the center lines for cylindrical features must always be shown.

In the circular view of a cylindrical object, the center lines are vertical and horizontal, with their intersection at the center of the circle (see Fig. 3-8). In the profile view, the center line coincides with the horizontal axis of the cylindrical form. Center lines should always extend slightly beyond the view, or feature of the view, to which they apply. Ordinarily, however, they should not be extended to connect views unless it is necessary to do so for dimensioning purposes.

Center lines are thin, fine lines made up of alternate long and short dashes. The long dashes are approximately $\frac{1}{2}$ to $1\frac{1}{2}$ in., and the short dashes are $\frac{1}{8}$ in., with spaces of about $\frac{1}{16}$ in. between them (see Fig. 3-6). Although center lines are usually straight, they may also be circular, as in the case of a center line for a bolt circle (see Fig. 7-21*a*, for example).

3-9. Precedence of lines. It is practically impossible to make a complete drawing without having some of the lines coincide. For example, a solid line may fall in the position of a hidden or center line, a hidden line may occur at the same spot as a center line, or a cutting-plane line may coincide with a center line (see Fig. 3-9).

The outer boundaries of a part are always solid lines. Since external features are of the utmost importance, at least for an intelligent reading of the drawing, solid lines always take precedence over any other coinciding lines. Hidden lines take precedence over center lines, although the center line may be extended as shown in the figure. If a cutting-plane line (see Sec. 8-12) and a center line coincide in a section view, the center line is shown instead of the line representing the imaginary cutting plane. Dimension lines and extension lines should never be placed to coincide with other lines in the drawing.

3-10. Line quality. In all freehand sketching, it is important that the first strokes of the pencil be light enough so that they may be corrected without disturbing too many other lines already drawn. If the beginner follows this practice, he will rarely need the eraser, for the light lines will apparently disappear or be absorbed during the finishing process when the weight and uniformity of all lines are being attended to.

In general, pencil lines should be reasonably straight, and black enough to produce an acceptable print if necessary. The size of the pencil point and the application of pressure on it will determine both the width and the intensity of the lines. In the finishing-up process, great care should be taken to make sure that there is sufficient contrast between each type of line—solid, hidden, or center (see Fig. 3-6). Any fuzziness or raggedness should

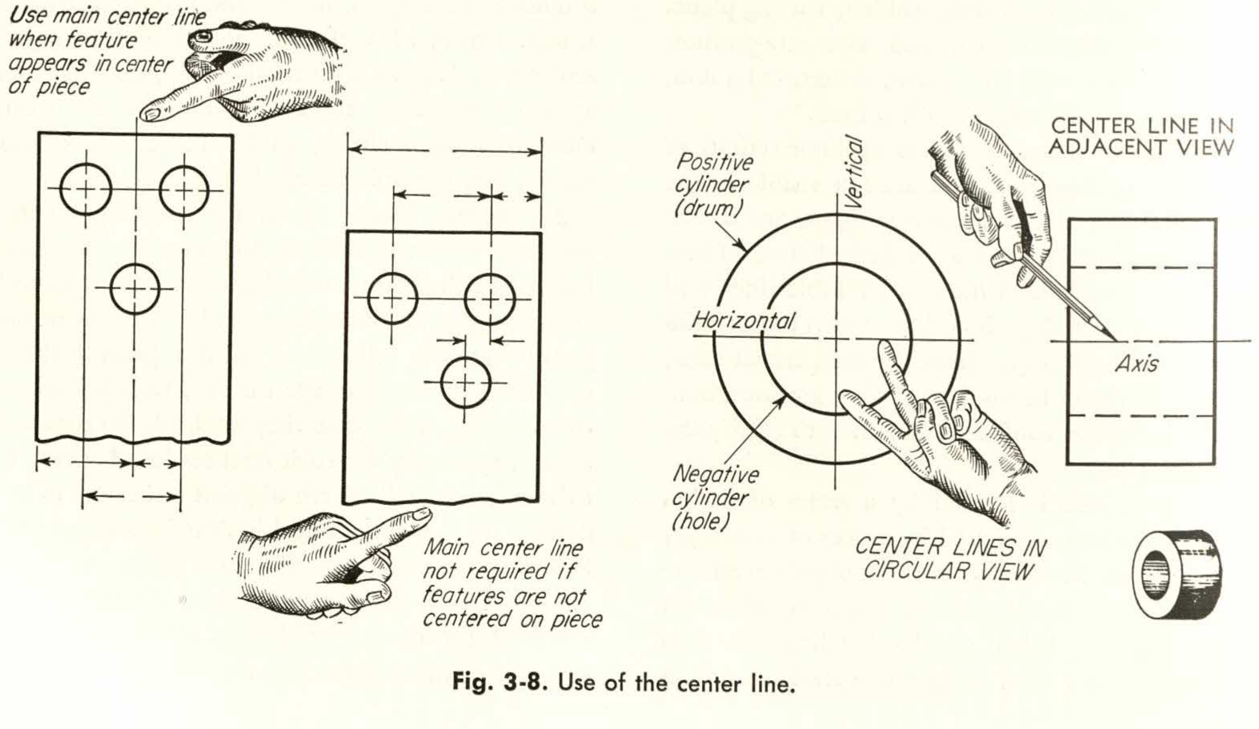

Use main center line when feature appears in center of piece
Main center line not required if features are not centered on piece
Positive cylinder (drum)
Vertical
Horizontal
Negative cylinder (hole)
CENTER LINE IN ADJACENT VIEW
Axis
CENTER LINES IN CIRCULAR VIEW

Fig. 3-8. Use of the center line.

be eliminated. Always pay particular attention to the arcs of circles, ellipses, and irregular curves to make sure that they are of the proper weight.

3-11. Circles and circle arcs. Circles may be easily sketched by first drawing horizontal and vertical lines through a point marking the center of the desired circle and then laying off the radius on these lines by eye or by the use of a scrap of paper on which the proper radial length has been marked (see Fig. 3-11). If the circle is small (less than approximately $\frac{3}{8}$ in.), it may then be drawn by sketching the arcs to connect the points. If large circles are to be produced, additional radii will facilitate the drawing of smooth arcs. In drawing the circle, the draftsman should sketch the first arc in the quadrant that seems most natural to him and then rotate the drawing paper so that the adjoining arc will appear and be drawn in the same quadrant.

3-12. The ellipse. In drawing a large ellipse, it is best to locate the long and short diameters within a rectangle and add inclined lines stemming from the center point, as shown in the first panel of Fig. 3-12. The points indicating the paths of the curves that form the ellipse are located on these lines by eye. A little practice will enable the beginner to swing in the needed curves smoothly and neatly. To draw a smaller ellipse, locate the long and short diameters within a rectangle, and lightly sketch straight lines joining the points where the diameters intersect the rectangle. Then mark points by eye at the center of the triangular areas thus formed, and draw the four required curves to complete the ellipse. In drawing either the large or the small ellipse, the paper should be rotated for convenience in the same manner used for drawing the arcs of the circle.

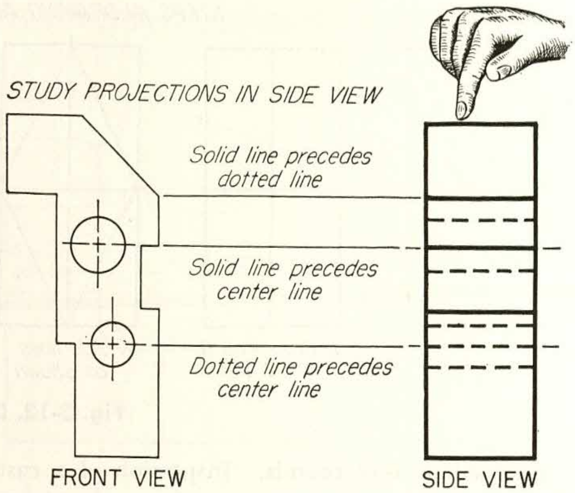

STUDY PROJECTIONS IN SIDE VIEW
Solid line precedes dotted line
Solid line precedes center line
Dotted line precedes center line
FRONT VIEW
SIDE VIEW

Fig. 3-9. Precedence of lines.

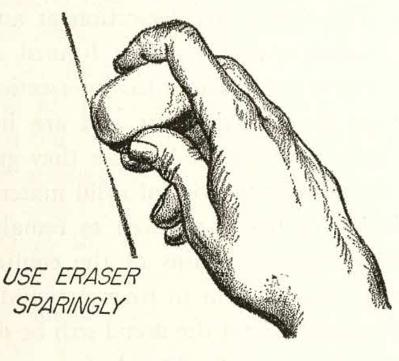


Fig. 3-10. The eraser.

3-13. The irregular curve. A satisfactory irregular curve can be produced by locating points at $\frac{1}{4}$- to $\frac{1}{2}$-in. intervals along its intended path, and then drawing a series of arcs through them (see Fig. 3-13).

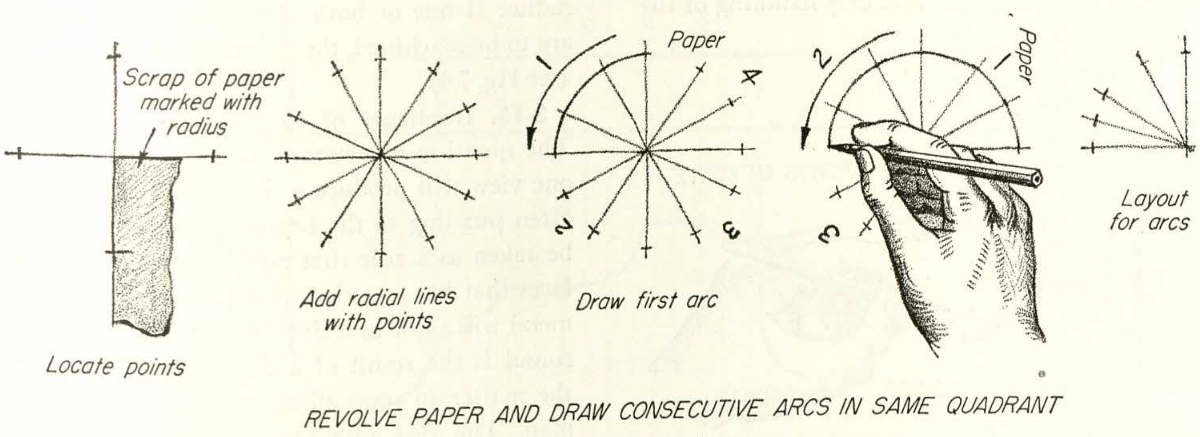

Scrap of paper marked with radius
Locate points
Add radial lines with points
Paper
Draw first arc
Paper
Layout for arcs
REVOLVE PAPER AND DRAW CONSECUTIVE ARCS IN SAME QUADRANT

Fig. 3-11. Drawing circles and circle arcs.

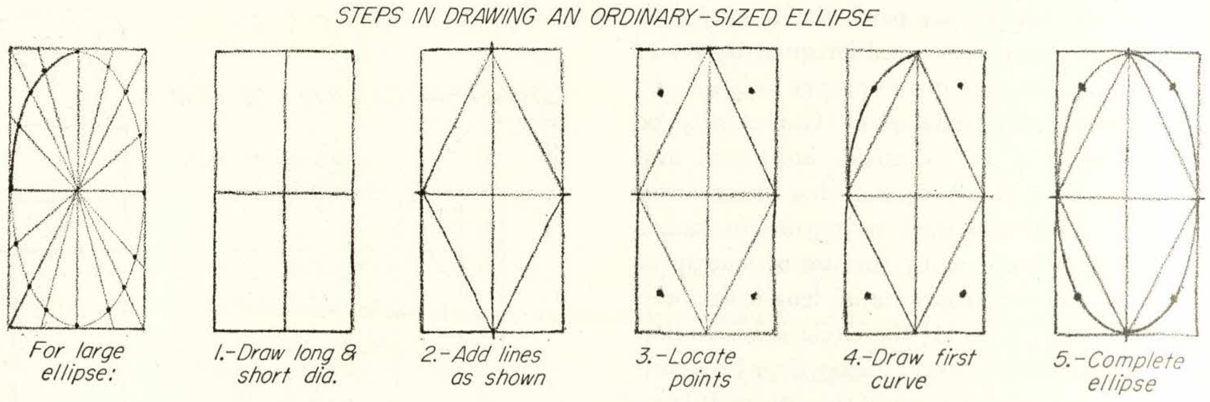


Fig. 3-12. Drawing the ellipse.

3-14. Fillets and rounds. Inspection of a casting immediately after its removal from a mold will reveal that the intersections of surfaces are slightly rounded. The rounded intersection at an outside corner is called a *round* and is formed naturally when the metal cools. Rounded intersections at inside corners are called *fillets* and are important from a design standpoint because they greatly affect the strength properties of solid materials. If a square inside corner is allowed to remain in the mold, the shrinkage strains of the cooling metal cause the grains to form in lines perpendicular to the cooling surface and the metal will be drawn inward, resulting in a weakened structure, with a possibility of the formation of cracks and even holes occurring at these corners in thin-walled sections. If the proper size of fillet is placed in the corner of the pattern by the patternmaker no crack will form in the casting (see Fig. 3-14).

Rounds, on the other hand, do not affect the strength properties materially and are of little importance in design, but they may improve the appearance and permit safe and easy handling of the casting. The size (the radius of the cross section) of a given round or fillet depends on the size of the piece, its function, the metal used in casting, and the amount of machining which may be required to bring it to its finished state.

In small objects, the fillets and rounds on cast iron are usually approximately $\frac{1}{8}$ in. in radius. On small aluminum, zinc, and other white-metal pieces, they are about $\frac{1}{16}$ in. In making a drawing, fillets and rounds should be shown at the intersections of unfinished surfaces. When an arc representing a fillet or round is small ($\frac{1}{8}$ in. or less), it should be drawn freehand, even in an instrument-produced drawing. If an arc is larger than $\frac{1}{8}$ in., use the method for drawing arcs illustrated in Fig. 3-11. A note on the drawing sheet such as "Fillets and rounds $\frac{1}{8}$"" is a direction to the patternmaker and will suffice as the dimensioning for all the ordinary fillets and rounds on a cast-iron piece. When a fillet or a round is large and approaches significance as a contour, its exact radius must be given on the view in which it appears in its true radius. If one or both of two intersecting surfaces are to be machined, the corner should appear sharp (see Fig. 7-4).

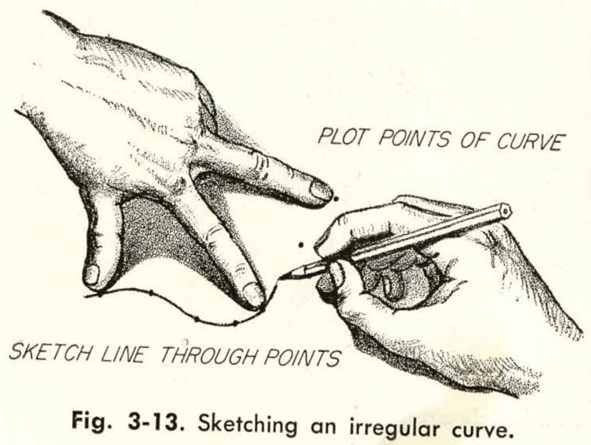


Fig. 3-13. Sketching an irregular curve.

3-15. Treatment of rounded forms and edges. The question of whether a round that appears in one view will produce a line in the related view is often puzzling to the beginning draftsman. It may be taken as a rule that an intersection of two surfaces that has rounded by a natural cooling of the metal will show as a line in the related view. If the round is the result of a design specification, then the matter in some measure rests with the draftsman. The two adjacent views in Fig. 3-15 have been prepared to help the draftsman with this

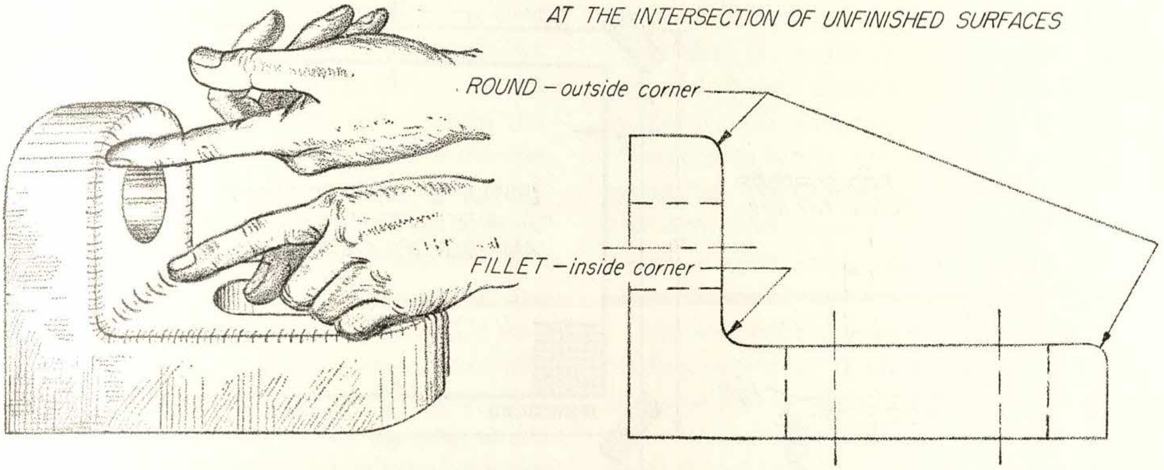


Fig. 3-14. Fillets and rounds.

problem. The profile view shows many of the rounded forms that will arise from time to time; the adjacent view shows the suggested treatment.

3-16. Producing a freehand orthographic detail drawing. Suppose that you are required to make an orthographic sketch of the object shown in the upper left-hand corner of Fig. 3-16. After selecting a sheet of paper of the cross-section type so that the squares may be used for gaging the dimensioning, the first step would be to lay out the borders on the drawing sheet as indicated in the upper right corner of the illustration, making the lines about as dark as the solid lines of the object will be.

Study the object carefully, and select a front view that will show its most characteristic shape, or the one that will require the least number of hidden lines. Next determine the least number of views required to describe the object adequately, again selecting those views that will mean the fewest hidden lines. At this point, it is helpful to form a mental picture of the general dimensions of each view so as to ensure good composition within the borders of the sheet. After the space between views and their arrangement on the sheet have been determined, locate the main center lines as shown in step 1. Once the center lines have been placed, block in the significant features of each view as shown in step 2, using the dimensions of the pictorial view. All views should be in direct projection with one another—the top above the front and the side at the right of the front—and should progress together. Next sketch in the circles and circle arcs (including fillets and rounds) as shown in step 3. In step 4, complete the circular forms, and show the hidden lines located in their proper positions.

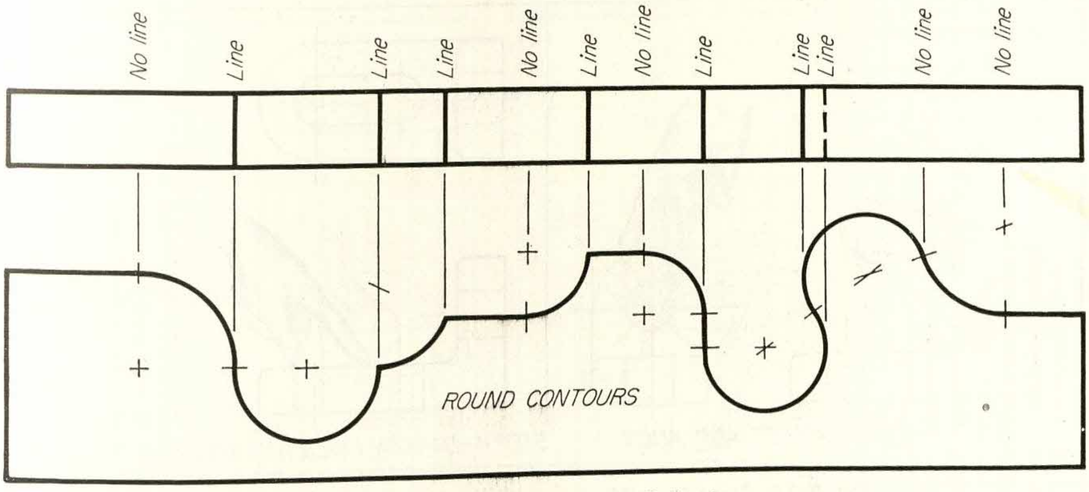
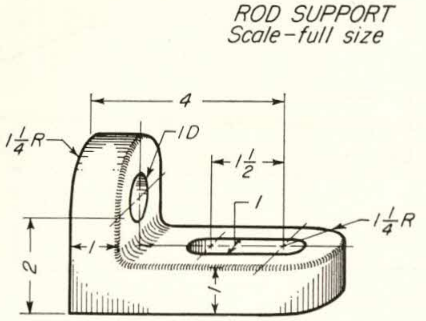
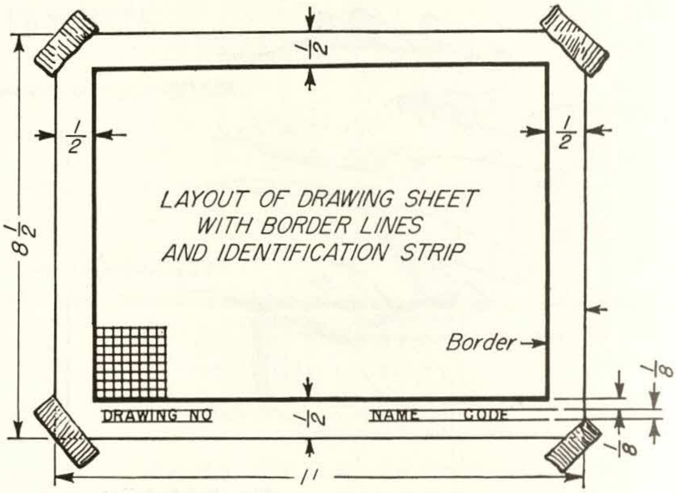


Fig. 3-15. Treatment of rounded edges.





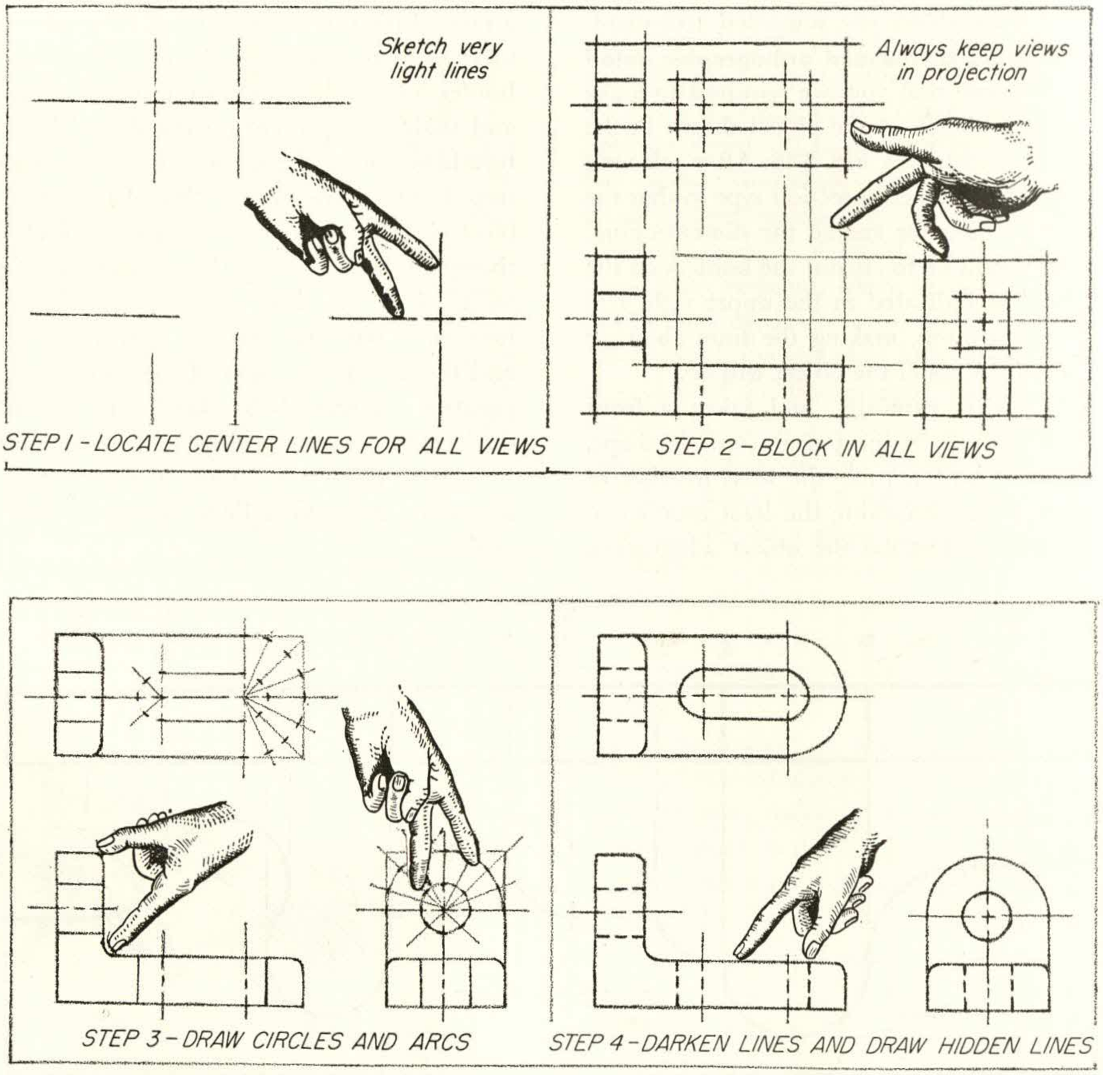

Sketch very light lines
STEP 1 - LOCATE CENTER LINES FOR ALL VIEWS
Always keep views in projection
STEP 2 - BLOCK IN ALL VIEWS
STEP 3 - DRAW CIRCLES AND ARCS
STEP 4 - DARKEN LINES AND DRAW HIDDEN LINES

Fig. 3-16. Steps in making an orthographic detail drawing.

The preliminary work on the drawing has been carried on with the harder pencil (2H). The softer pencil (HB) should now be employed to darken the lines to the desired blackness and crispness and to bring about a proper contrast between the medium-width hidden lines, the wider object lines, and the thin center lines. It should be kept in mind that the width of a line and its blackness or intensity are determined by the manipulation of the pencil and the pressure applied. If reasonable care has been used in the preparatory work, there will be only a few lines that will have to be erased.

3-17. Spacing the views on the drawing sheet. If the drawing is to be dimensioned (the beginner should not attempt to dimension his drawing until he is fully acquainted with the dimensioning rules outlined in Chap. 7), the locations of notes and dimensions will in some measure influence the position of the views in relation to each other and as a group within the borders of the sheet (see Fig. 3-17). As a general rule, however, considering *A* as the unit dimension, *B* should be approximately equal to $\frac{3}{4}A$ and *C* approximately equal to $\frac{3}{4}B$. Sufficient space must be left between views to allow for dimensioning, since one of the fundamental rules of drafting states that dimensions should be placed between views wherever possible. The drawing at the right in Fig. 3-17 shows an acceptable arrangement of a two-view drawing with complete dimensions and notes.

3-18. The title block. In general, the title block appears just inside the border lines at the lower right corner of the sheet. It is sometimes accompanied by a record strip that lies to the left of the block along the top of the lower border. The drafting and design divisions of many of the larger manufacturing companies use drawing sheets with printed title blocks that seem best suited to their particular manufacturing procedures (see Fig. 3-18). Smaller concerns often purchase ready-cut paper or cloth sheets with a blank title block already imprinted upon them. See Sec. 13-3 also.

The information listed in a title block may vary slightly depending on the object being drawn and the standards of the company for which the drawing is being prepared. However, in general the title block should list:

1. Name and address of the company
2. Name of the machine or unit (if assembly) or name of the part (if a single piece)
3. Drawing number
4. Number of parts required (if assembly) or the number of the part (if a detail drawing)
5. Scale
6. Date
7. Name of draftsman
8. Name of tracer
9. Name of checker
10. Name of man who approved final drawing

When necessary, the title block or record strip should also include information concerning material, stock sizes, heat-treatment, finishes, corrections and revisions, etc.

All lettering in the title block should be in capitals (see Fig. 13-4 for additional information on the preparation of a title block).

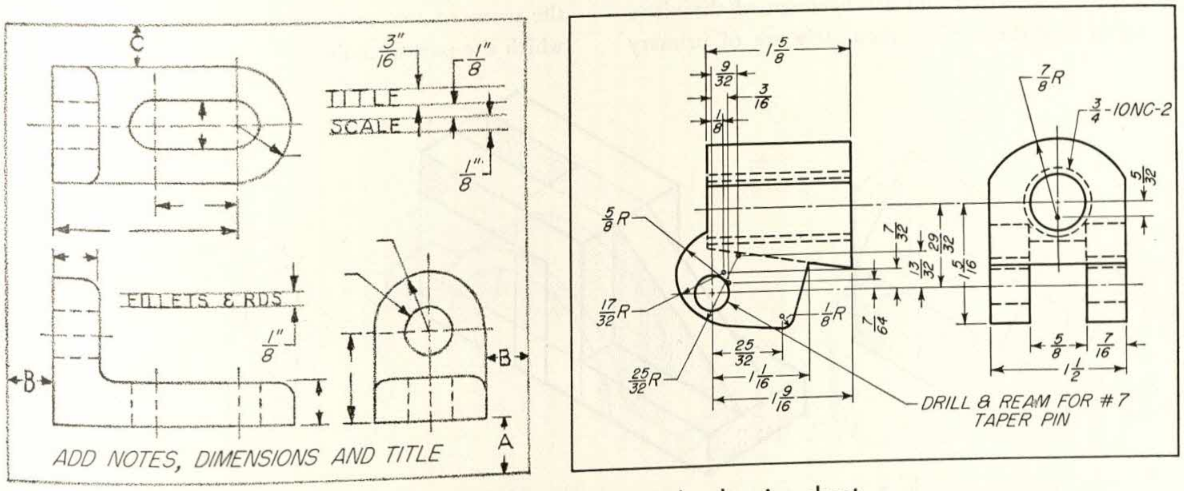


Fig. 3-17. Spacing the views on the drawing sheet.

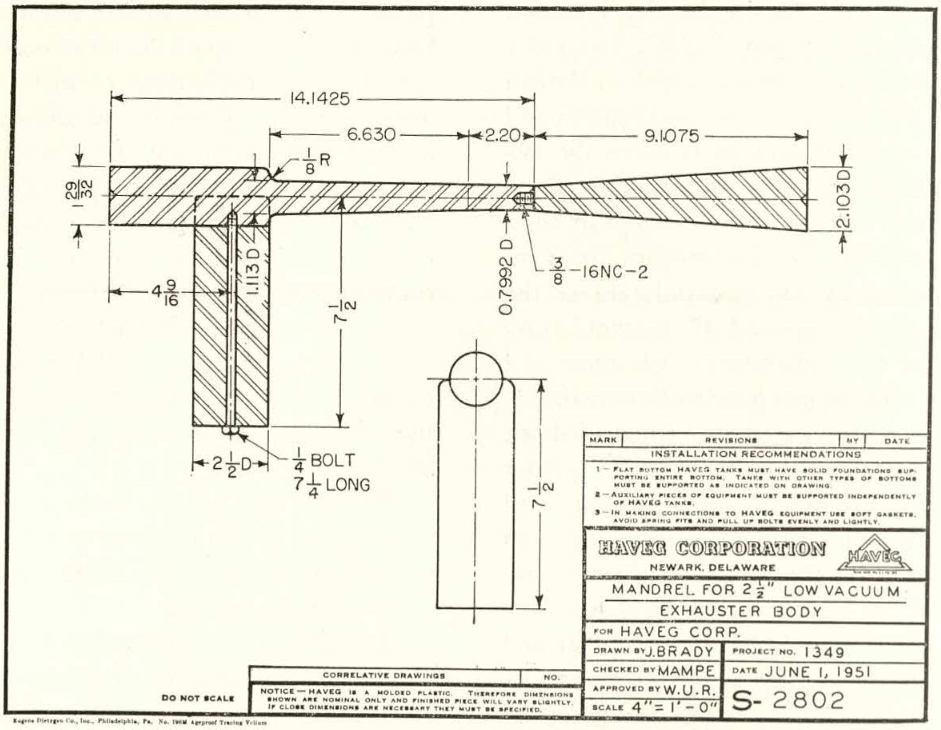

14.1425
6.630
2.20
9.1075
$\frac{1}{8}$R
$1\frac{29}{32}$
2.103 D
1.113 D
$4\frac{9}{16}$
$7\frac{1}{2}$
0.7992 D
$\frac{3}{8}$-16NC-2
$2\frac{1}{2}$D
$\frac{1}{4}$ BOLT
$7\frac{1}{4}$ LONG
$7\frac{1}{2}$
MARK
REVISIONS
BY
DATE
INSTALLATION RECOMMENDATIONS
1 — FLAT BOTTOM HAVEG TANKS MUST HAVE SOLID FOUNDATIONS SUPPORTING ENTIRE BOTTOM. TANKS WITH OTHER TYPES OF BOTTOMS MUST BE SUPPORTED AS INDICATED ON DRAWING.
2 — AUXILIARY PIECES OF EQUIPMENT MUST BE SUPPORTED INDEPENDENTLY OF HAVEG TANKS.
3 — IN MAKING CONNECTIONS TO HAVEG EQUIPMENT USE SOFT GASKETS. AVOID SPRING FITS AND PULL UP BOLTS EVENLY AND LIGHTLY.
HAVEG CORPORATION
NEWARK, DELAWARE
HAVEG
MANDREL FOR $2\frac{1}{2}$" LOW VACUUM EXHAUSTER BODY
FOR HAVEG CORP.
DRAWN BY J. BRADY
PROJECT NO. 1349
CHECKED BY MAMPE
DATE JUNE 1, 1951
APPROVED BY W.U.R.
SCALE 4" = 1' - 0"
S- 2802
CORRELATIVE DRAWINGS
NO.
NOTICE — HAVEG IS A MOLDED PLASTIC. THEREFORE DIMENSIONS SHOWN ARE NOMINAL ONLY AND FINISHED PIECE WILL VARY SLIGHTLY. IF CLOSE DIMENSIONS ARE NECESSARY THEY MUST BE SPECIFIED.
DO NOT SCALE
Eugene Dietzgen Co., Inc., Philadelphia, Pa. No. 196M Ageproof Tracing Vellum

Fig. 3-18. The title block. (*The Haveg Corporation.*)

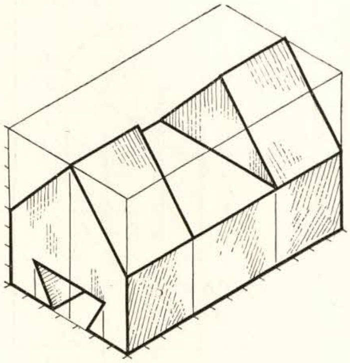
PROBLEMS

The problems in this group should be drawn freehand (without kit instruments) on 8½- by 11-in. cross-section paper with a ½-in. border. The student is not expected to dimension any of the problems until he has familiarized himself with correct dimensioning procedures as explained in Chap. 7.

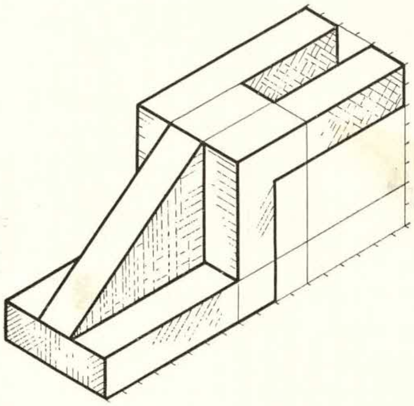
These problems have been selected to illustrate the proper application of the principles of orthographic projection, the technique of pencil sketching, and the proper use of the chart showing the classification of lines. Since the selection and arrangement of the views necessary to describe a piece accurately are of primary importance to a successful presentation, it is suggested that the student make a thumbnail sketch on scratch paper for each layout before proceeding with the drawing on the final sheet.

The dimensions of the objects shown in Probs. 3-1 to 3-12 may be determined by the ¼-in. markings. Problems 3-13 to 3-26 have figured dimensions so that the instructor may also assign them as dimensioning problems following the study of Chap. 7.

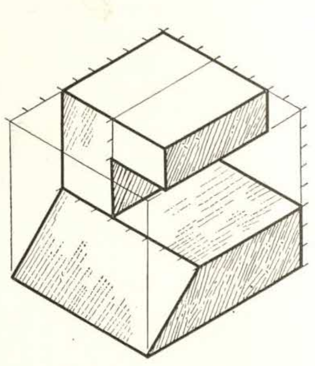
Show a simple title block for each problem, indicating the name of the part, the scale, and the material from which the part is made.



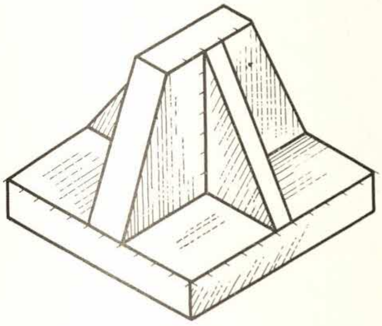
3-1. Sliding rest, steel. Draw three views.



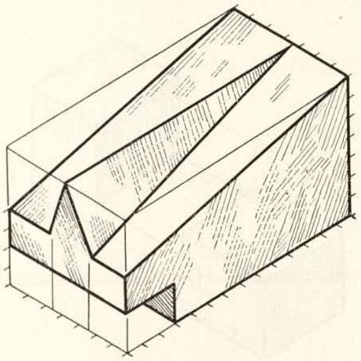
3-2. Frame support, cast iron. Draw three views.



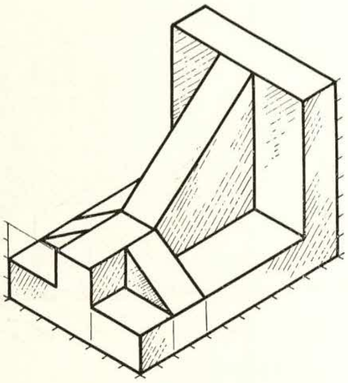
3-3. Gage block, steel. Draw three views.



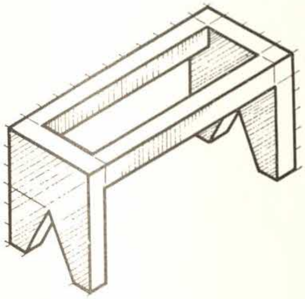
3-4. Corner support, cast iron. Draw three views.



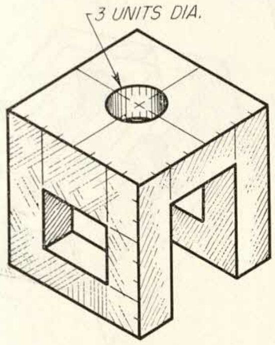
3-5. Gage block, steel. Draw three views.



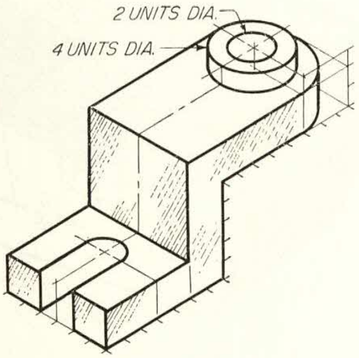
3-6. Bracket, cast iron. Draw three views.



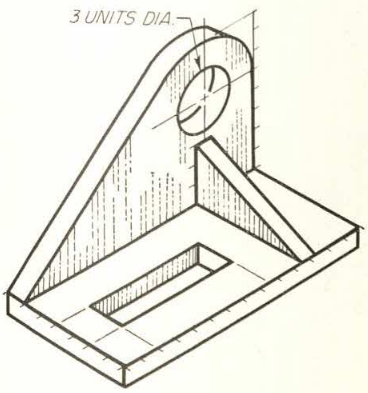
3-7. Motor support, steel. Draw three views.



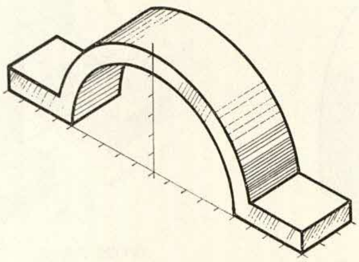
3-8. Fixture, cast iron. Draw three views.



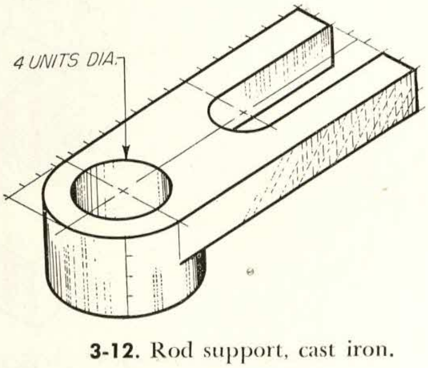
3-9. Rod guide, cast iron. Draw two views.



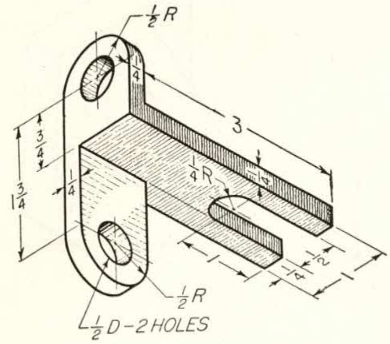
3-10. Bracket, cast iron. Draw three views.



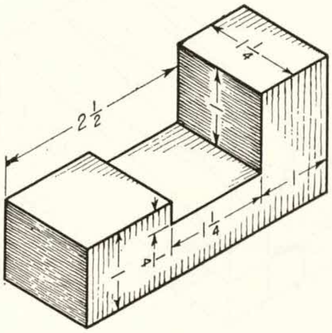
3-11. Clamp, steel. Draw two views.



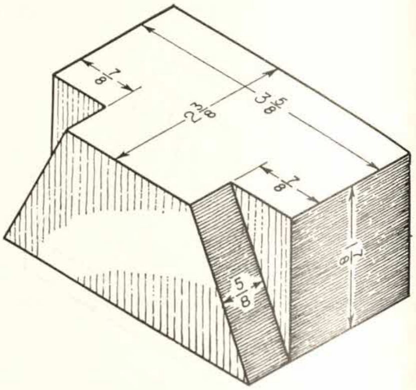
3-12. Rod support, cast iron. Draw two views.



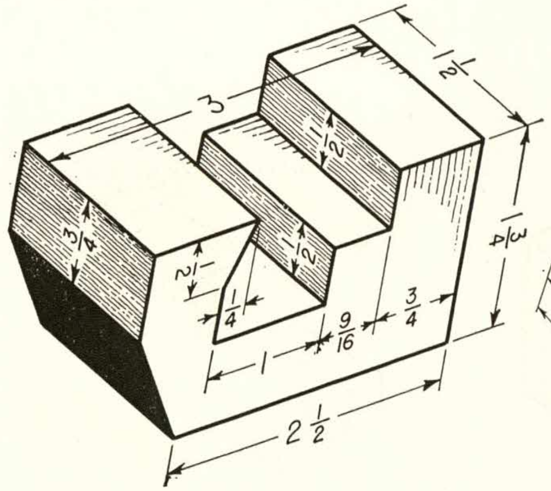
3-13. Rod guide, steel. Draw three views.



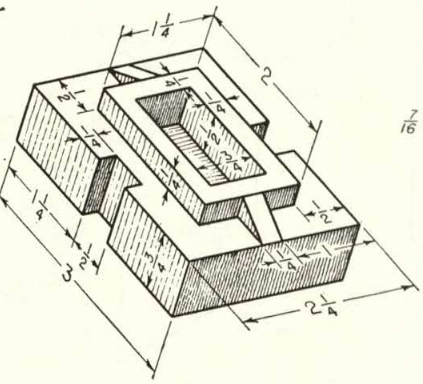
3-14. Block, cast iron. Draw three views.



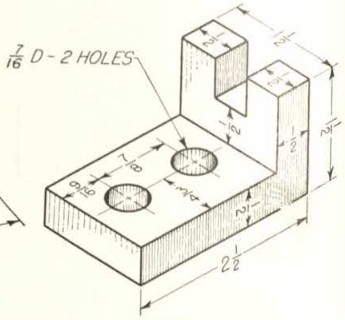
3-15. Guide block, cast iron. Draw three views.



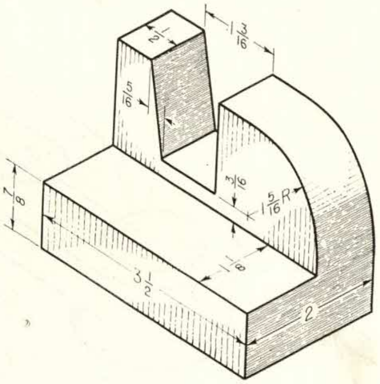
3-16. Gage block, steel. Draw three views.



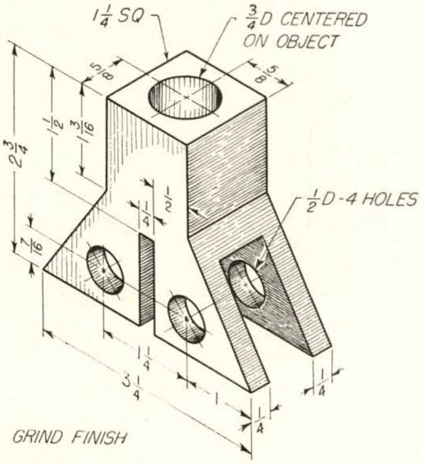
3-17. Column base, cast steel. Draw three views.



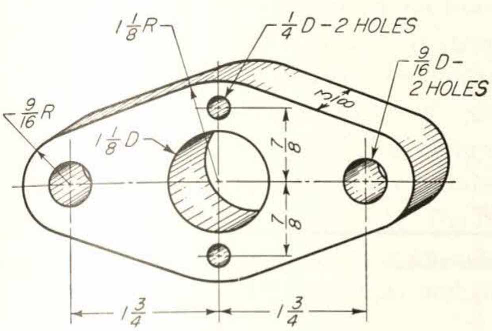
3-18. Stop block, cast iron. Draw three views.



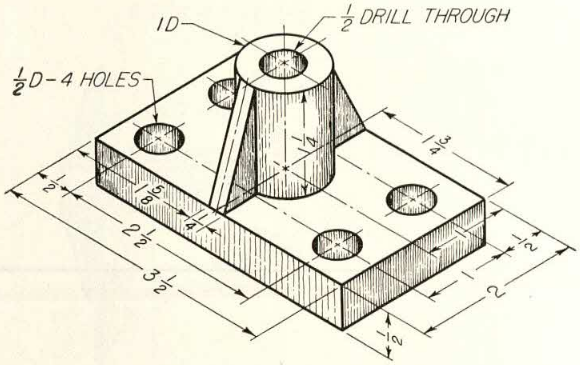
3-19. Tool rest, steel. Draw three views.



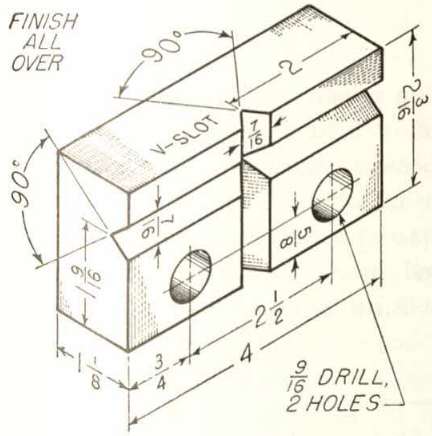
3-20. Base connector, steel. Draw three views.



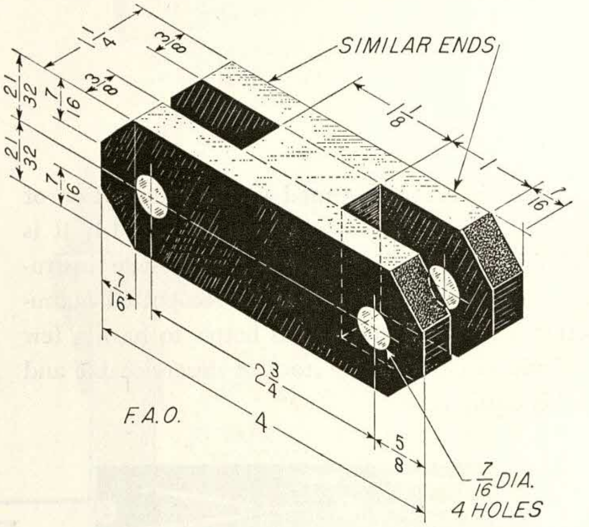
3-21. Cover plate, cast iron. Draw two views.



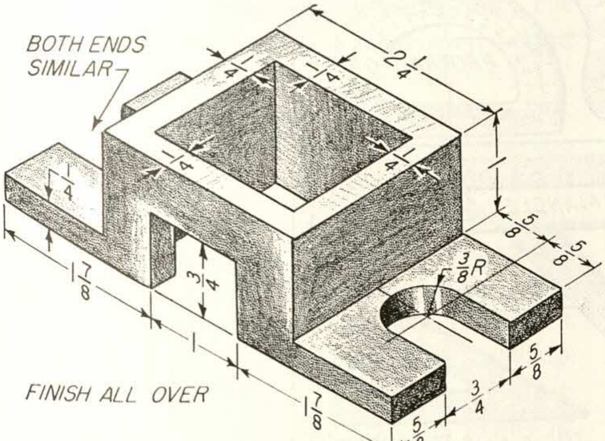
3-22. Rod support, cast iron. Draw two views.



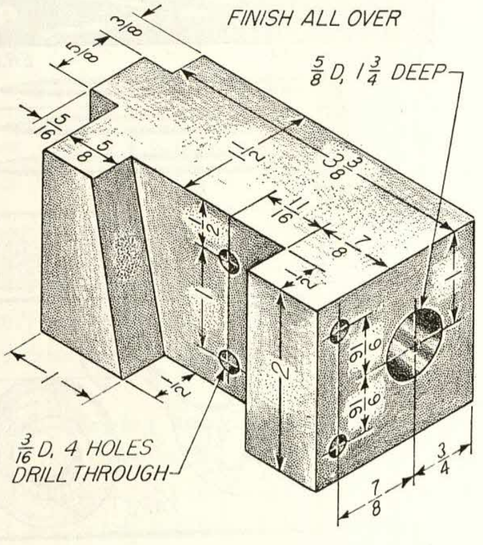
3-23. Vise jaw, steel. Draw three views.



3-24. Link, steel. Draw two views.



3-25. Lock catch, brass. Draw three views.



3-26. Taper fixture, steel. Draw three views.

Chapter 4

INSTRUMENTS AND THEIR USE

The tools ordinarily used in the preparation of engineering drawings are shown in Fig. 4-1. It is advisable to secure simple but well-made instruments placed on the market by recognized manufacturers of these items. It is better to have a few good pieces than a large stock of unserviceable and shoddy equipment.

4-1. Drawing paper. The drawing papers come in white, buff, or light green. Rag-content papers, although expensive, afford excellent erasing qualities and can withstand frequent handling. The colored papers also permit frequent handling without soiling and, in addition, minimize eyestrain. A paper with sufficient grain to produce sharp, clean

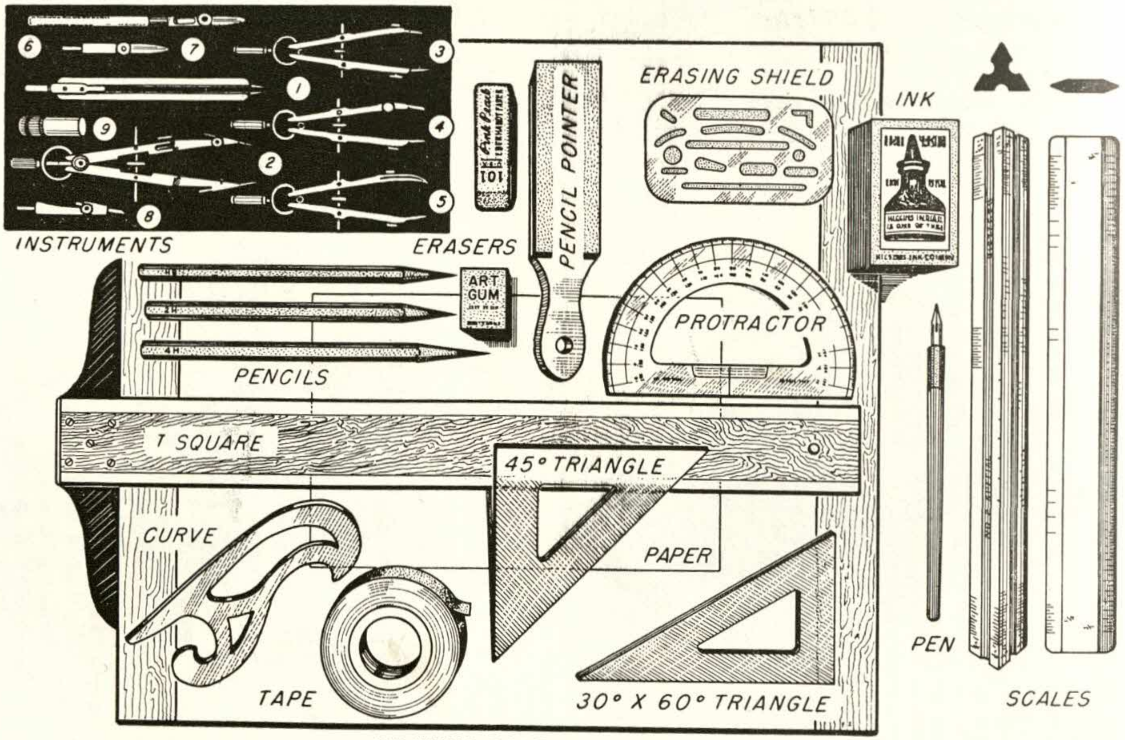


Fig. 4-1. The draftsman's working equipment.

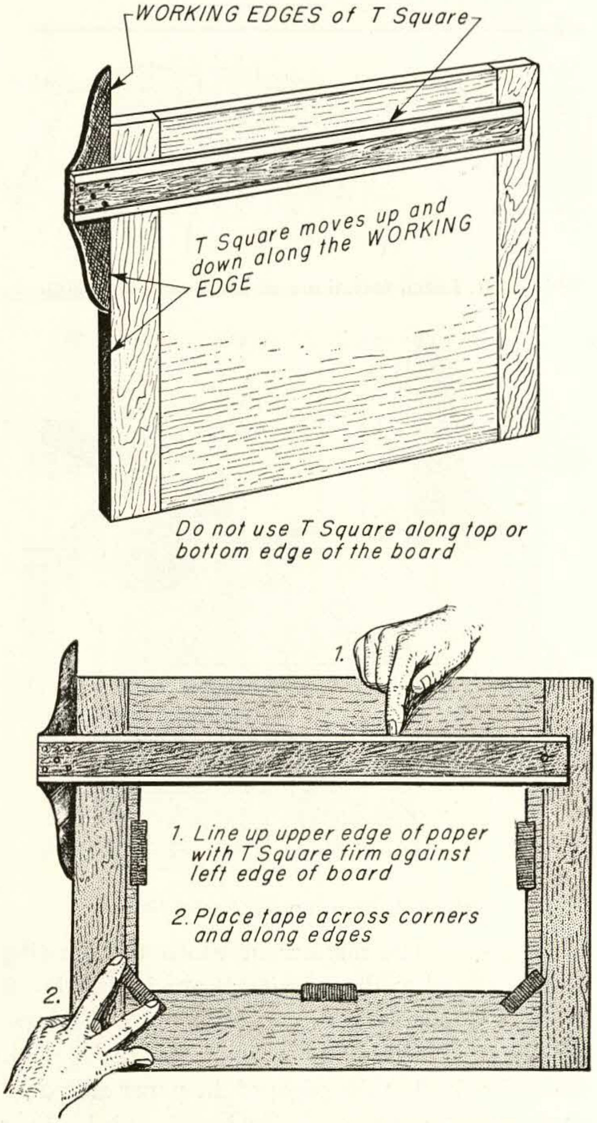
lines is desirable for pencil drawings or for color work. A smoother surface is better for fine ink ruling and all complicated drawing. Drawing paper may be purchased in rolls or sheets. The rolled paper comes in lengths of 10 to 20 yd and in widths between 30 and 58 in. The more common sheet sizes are proportioned to the ordinary letter sheet, that is, 8½ × 11, 11 × 17, etc. The American Standards Association (ASA) recommends the following sheet sizes for drawing paper and cloth:

A	8½ × 11
B	11 × 17
C	17 × 22
D	22 × 34
E	34 × 44

4-2. Tracing paper. Tracing paper comes in a white or blue tint. The better type has an unglazed and fairly smooth surface. It should be oil- and wax-free and sufficiently transparent to allow the preparation of clear blueprints and Ozalid reproductions from both pencil and ink drawings. The erasable quality of the tracing paper is an important factor. Tracing paper is available in standard-sized sheets and in rolls of 10 to 20 yd.

4-3. Tracing cloth. Cloth used for tracing is also commonly available in a white or blue tint. The better cloths are manufactured without the use of oil, wax, or grease to gain transparency. They are strong and tough and will not discolor with age, nor will they leave ghost marks when erased repeatedly. For these reasons, cloth is more satisfactory than tracing paper for most types of work, but it is more expensive. Most tracing cloths are prepared with a glazed and an unglazed surface. Pencil work is done on the unglazed surface. The better cloths, with excellent transparency, permit the making of all types of reproductions.

4-4. Use of paper, cloth, and tracing paper. The draftsman should be able to produce acceptable drawings on all types of drawing surfaces. In working the problems in this book, the student will first become familiar with drawing on cross-section paper in the chapter on freehand drawing. In working the problems in the chapters calling for instrument work, the first five or six drawings should be done on paper (white, buff, or light-green opaque); thereafter, the drawings should be produced on tracing paper. A few drawings should also be done on tracing cloth so that the student will become familiar with this material. The general practice in industry today is to use tracing paper or cloth for all working drawings. Tracing paper is used for most work, while tracing cloth is used for drawings which are likely to be heavily corrected or for those which are to be preserved.


WORKING EDGES of T Square
1.
2.

T Square moves up and down along the WORKING EDGE

Do not use T Square along top or bottom edge of the board

1. Line up upper edge of paper with T Square firm against left edge of board

2. Place tape across corners and along edges

Fig. 4-2. The drawing board and its use.

All drawings should be done in pencil. Ink is used only for permanent work, and even then the work is done first in pencil and afterward traced in ink.

4-5. The drawing board. In order to prevent warping, the drawing board is made of narrow strips of well-seasoned softwood with two drawing surfaces. Both ends are true, and either may be used as a working edge for the head of the T square (see Fig. 4-2). One standard-sized board measures

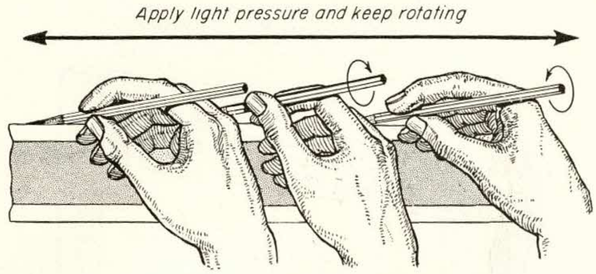

Apply light pressure and keep rotating

Fig. 4-3. Pencil technique in instrument drawing.

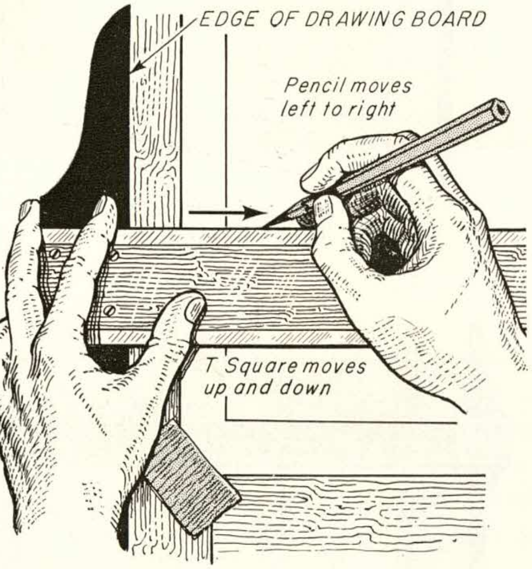

EDGE OF DRAWING BOARD
Pencil moves left to right
T Square moves up and down

Fig. 4-4. Drawing horizontal lines.

20 by 26 in. The manner in which the drawing sheet is affixed to the drawing board is also shown in Fig. 4-2. It should be attached firmly to the drawing board, preferably by taping down the corners. Make certain that the edges of the paper are parallel to the sides of the drawing board (this is of the utmost importance in instrument representations) and that the sheet lies flat, without wrinkles.

To prevent the pencil following the grain of the wood and to give better opacity, it is advisable to place a backing sheet of heavy white paper between tracing papers and the board.

4-6. Pencils. Pencils are available in 17 degrees of hardness. They range from the very hardest, 9H, through the medium grades, H, F, and HB, to the softest, 6B. Their hexagonal shape permits a sure grip on the flat planes of the sides. In a satisfactory drafting pencil, both the lead and the wood will sharpen easily and smoothly. When swept across the drawing sheet, the sharpened point should convey the velvety feeling of being free of grittiness of any kind. Selection of the proper pencil for the purpose at hand depends greatly on the smoothness or roughness of your drawing sheet and the width and "blackness" of line desired. In general, the 4H is used for the preliminary layout work, and the finishing up is accomplished with the 2H. One of the medium grades, an F or HB, is best for freehand mechanical sketching. (It should be pointed out here that all pencil lines on the drawing sheet should be of the same even, glossy "blackness." The contrast between thick, medium, and thin lines should be apparent because of their relative widths and not for individual black and gray qualities.)

Mechanical pencils have the advantage of remaining constant in length. Only the leads (all degrees are obtainable) need sharpening.

4-7. Pencil technique in instrument drawing. Since nearly all commercial drafting is done on tracing paper with the pencil, developing a reasonable skill in its use is important. A satisfactory pencil technique which will enable you to develop a style of your own can be acquired by conscientious adherence to several helpful suggestions. Start your layout by drawing in all the views lightly. This will facilitate any needed changes or corrections before going over the lines to produce their final proper density or contrast. When tracing paper is used, this final density can be secured by the application of a slight pressure on the pencil, which is slowly rotated between the thumb and fingers as it moves against the straightedge, back and forth, in both directions, without being lifted from the surface of the paper. A stroke of the brush removes any loose particles of graphite, and smudging by the passage of the T square or triangles over the line is greatly reduced. If the pencil is not rotated, a "flat" that increases in size as the work progresses will form at the tip to produce lines of increasing width. Since the pencil is inclined about 30° in the direction of the line being drawn, this rotation will tend to keep the point rounded and the width of the line uniform for a longer time (see Fig. 4-3).

4-8. The T square. There are several types of T squares available for drawing purposes. They may be made of steel or wood. The T square should be approximately the same length as the drawing board and should be well made of wood that will not warp. One of the most serviceable types of T square is made with transparent recessed edges that permit viewing of the lines underneath the edge of the blade and avoid blotting in using ink. The edge should be straight, free of scratches or nicks.

The straight horizontal lines on a drawing are produced with the T square (see Fig. 4-4). The T square slides up and down along the left edge of the drawing board. The points that are to locate the lines are placed as close as possible to the left side of the drawing surface. With the pencil point resting very close to the bottom of the top edge of the T square and the head of the T square firm against the left edge of the board, the lines are drawn from the locating points toward the right. Ordinarily, the horizontal lines at the top of a drawing are produced before those below. A T square should never be used to draw vertical lines by placing the head of the instrument along the top or bottom of the drawing board, with the blade thus vertical.

4-9. The triangles. The triangles most desired by professional draftsmen are made of clear plastic and retain their shape and stability indefinitely. They do not mar and scratch easily or discolor with age. They should be flexible, with no evidence of warpage, and should be large enough to permit the drawing of a vertical line of at least 8 in. in length without lifting the pencil. The 30°-60° and the 45° triangles are primarily used for the drawing of straight vertical and inclined lines. Besides the 30°-60° and the 45° triangles, there are others that have many and varied uses, among them being the lettering angles. These are generally designed to give a quick and easy method of making accurately spaced guide lines for the lettering and figure work appearing on drawings. See Sec. 1-6.

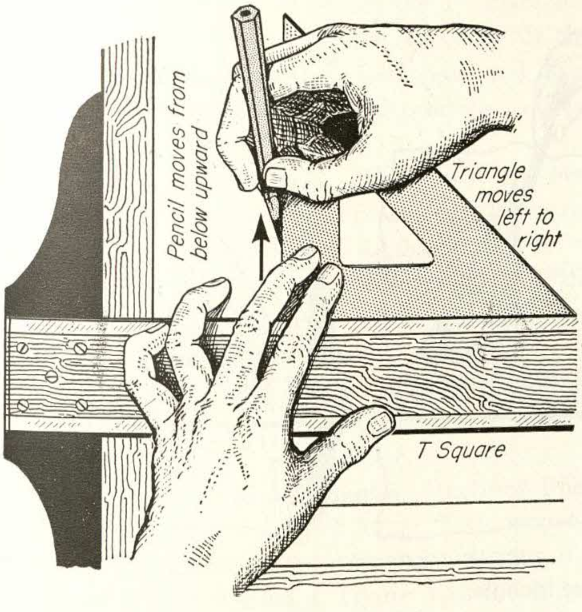

Pencil moves from below upward
Triangle moves left to right
T Square

Fig. 4-5. Drawing vertical lines.

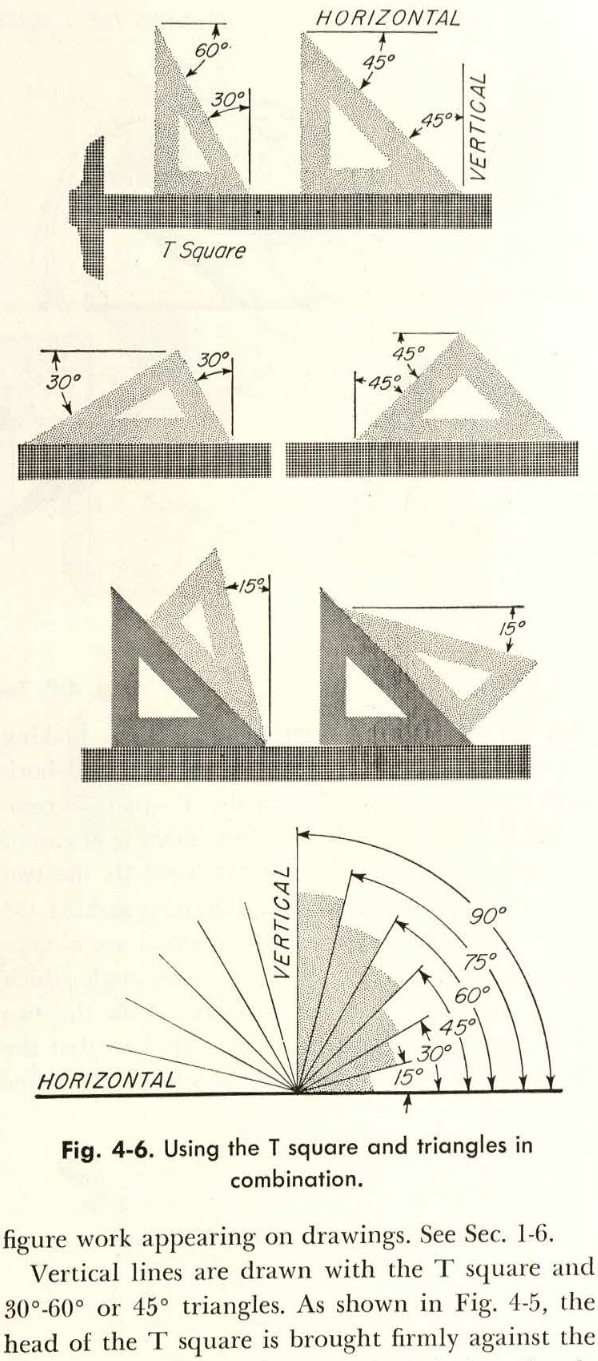


Fig. 4-6. Using the T square and triangles in combination.

Vertical lines are drawn with the T square and 30°-60° or 45° triangles. As shown in Fig. 4-5, the head of the T square is brought firmly against the left edge of the drawing board, and the triangle is placed in position against the top edge of the T-square blade. The vertical line is drawn upward along the edge of the triangle. The lines at the left side of the sheet are drawn first. By sliding the triangle toward the right and always keeping it in contact with the T square, additional parallel vertical lines may be produced. The pencil lead and the edge of the triangle must make close contact to produce an even, true line.

As illustrated in Fig. 4-6, with the T square

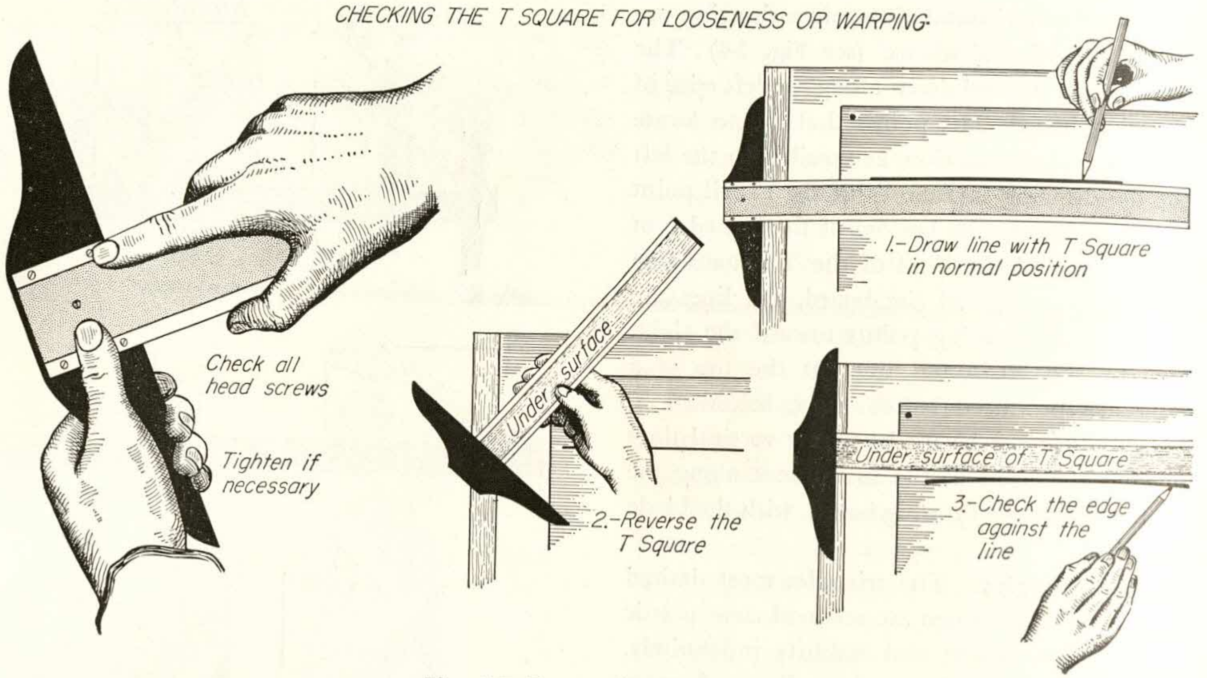

CHECKING THE T SQUARE FOR LOOSENESS OR WARPING
Check all head screws
Tighten if necessary
1.-Draw line with T Square in normal position
Under surface
2.-Reverse the T Square
Under surface of T Square
3.-Check the edge against the line

Fig. 4-7. Testing the T square.

and 30°-60° triangle combination, lines making angles of 30° and 60° with the vertical and horizontal may be drawn. When the T square is combined with the 45° triangle, lines making angles of 45° with the horizontal are produced. If the two triangles are used in combination, lines making 15° angles with the vertical and horizontal are obtainable; therefore, any line that is at an angle which is a multiple of 15° can be drawn with the two triangles and T square. It is also obvious that the 45° triangle will divide a circle into 4 or 8 parts. The 30°-60° triangle will divide a circle into 6 or 12 parts, and the two triangles in combination will produce 24 equal portions of a circle (see the bottom part of Fig. 4-6).

4-10. Testing the T square, triangles, and drawing board. It is obvious that the draftsman can do accurate work only as long as his instruments remain "true" and in proper working order. Therefore, the student, as well as the practicing draftsman, should form the habit of frequently checking the tools with which he works.

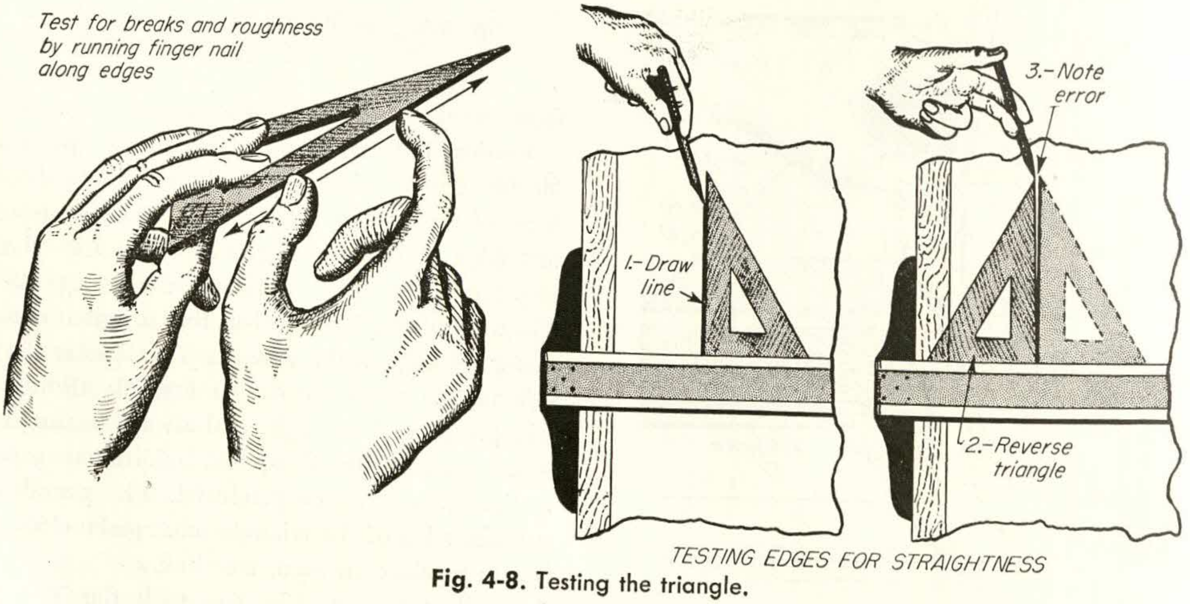

Test for breaks and roughness by running finger nail along edges
1.-Draw line
2.-Reverse triangle
3.-Note error
TESTING EDGES FOR STRAIGHTNESS

Fig. 4-8. Testing the triangle.

The screws that attach the blade of the T square to the head should be tight; otherwise, there may be horizontal play in the T-square blade. The working edge of the T-square blade may be checked for straightness by very carefully drawing a sharp line through two widely separated points and then turning the T square over and drawing another line through the points along the same edge of the blade (see Fig. 4-7). If the lines do not coincide, or if there are marks and scratches in the blade, the error may be corrected by scraping and sandpapering the defective edge.

The edges of triangles may be checked for straightness in the manner illustrated in Fig. 4-8. They may be tested for breaks and roughness by running a fingernail along the edges. As was the case with the T square, defects in the edges of the triangles should be removed by scraping and sandpapering.

The drawing board should always be wiped or dusted before it is used in order to assure a clean working surface and to remove any particles that might cause the pencil to break through the drawing sheet. The working edge of the board may be tested by laying the head of a T square that is known to be true along the edge of the drawing board, as illustrated in Fig. 4-9. The T square should touch the drawing board along its entire length, and no light should be visible between the edges.

4-11. Parallel lines. To draw a line parallel to another line (Fig. 4-10), place the T square and triangle in combination so that the edge of the triangle coincides with the given line, and then slide the triangle to the required position to draw the other line.

4-12. Perpendicular lines. To draw a line perpendicular to another line, place the T square and triangle in combination so that one edge of the triangle coincides with the given line. Then slide the triangle to the required position, and draw the desired perpendicular line along the other leg (see Fig. 4-11). If the use of the T square in these steps is awkward, another triangle may be substituted for it as a straightedge.

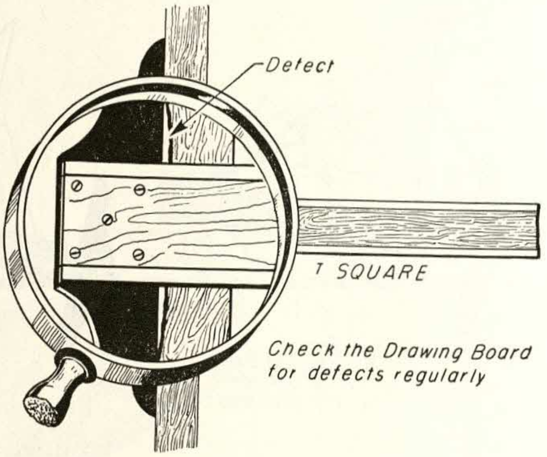


Fig. 4-9. Testing the edge of the drawing board.

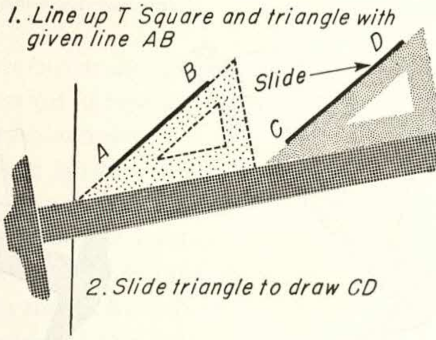

1. Line up T Square and triangle with given line AB
D
B
Slide
C
A
2. Slide triangle to draw CD

Fig. 4-10. Drawing parallel lines.

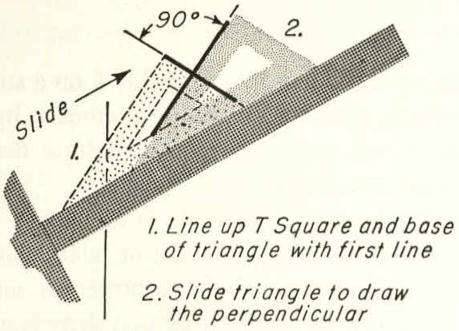
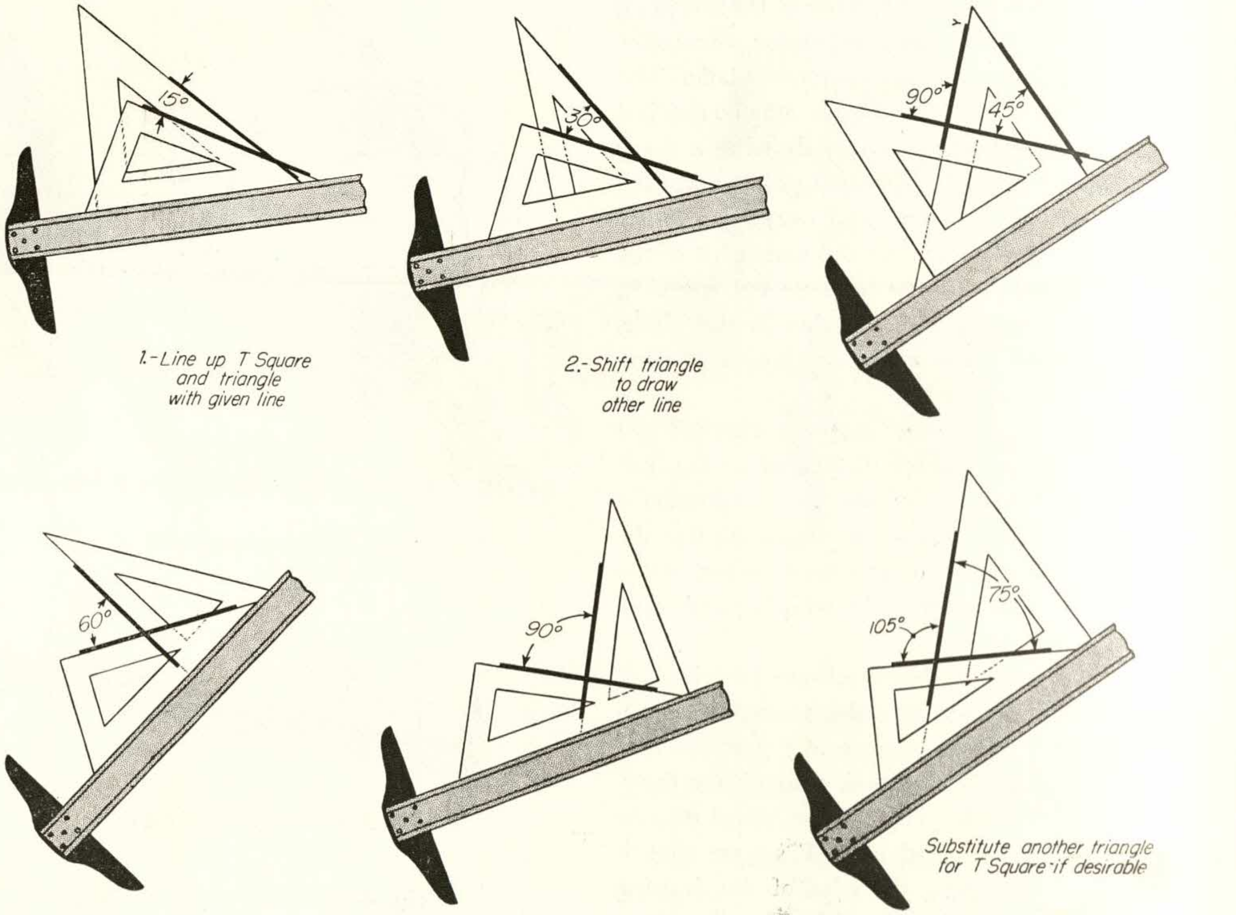

90°
1.
2.
Slide
1.
1. Line up T Square and base of triangle with first line
2. Slide triangle to draw the perpendicular

Fig. 4-11. Drawing perpendicular lines.

4-13. Inclined lines and angles. Inclined lines making 15° increments with other lines may be drawn by manipulating the triangles and using the T square as a straightedge. Figure 4-12 illustrates the procedure of drawing lines at various angles. Note that in some instances the 45° triangle or the 30°-60° triangle is used alone to get the resulting angle; in other cases, the two triangles are used in combination.

4-14. Joining two points. Figure 4-13 shows an easy method of joining the two points that mark a measurement. With the pencil point firmly placed on point *A*, slide the triangle up to meet it; then, pendulumlike, swing the lower portion of the



1.-Line up T Square and triangle with given line

2.-Shift triangle to draw other line

Substitute another triangle for T Square if desirable

Fig. 4-12. Drawing inclined lines and angles.

triangle until the leg lines up point *B* on a straight line with *A*. Check point *B* for alignment by putting the pencil point on it; then draw the line joining the two points.

4-15. The scale. The scale is actually a measuring stick. Scales are either flat or triangular, and the material used in their construction may be wood, celluloid, or metal. Although there is a great variety of scales available for special purposes and for different uses in the various engineering professions, scales that the draftsman will use are of two basic types. The scale most commonly used is called the architect's scale. It is divided into the familiar units of inches and fractions of an inch. This scale is usually *open-divided,* which means that only the units of the full-size scale and the end unit of the other scales are subdivided into small fractions of an inch.

The second basic type of scale is the engineer's scale. It is usually divided into decimal parts of an inch, starting with 10 divisions to the inch along one edge and ranging to 50 or more decimal divisions to the inch along the other edges. The engineer's scale is usually *full-divided,* since the equal divisions and subdivisions are carried along the entire edge of the various scales, there being but one kind of division along each edge.

The divisions on the scales enable the draftsman to prepare drawings to actual size, enlarged, or reduced, as required. The architect's scale is used to represent a scale in inches or fractions of inches to the foot (for example, $6'' = 1'\text{-}0''$ or $1\frac{1}{2}'' = 1'\text{-}0''$); the engineer's scale, with its decimal divisions, is used to represent inches to the foot (for example, $1'' = 10'$). The latter type is therefore used for decimal dimensioning and for map drawing and plotting.

4-16. Use of the scale. The scale should never be used as a straightedge. The purpose of the scale is to transfer to the drawing the true relative dimensions of an object. Although the drawing itself may appear enlarged or reduced in scale depending

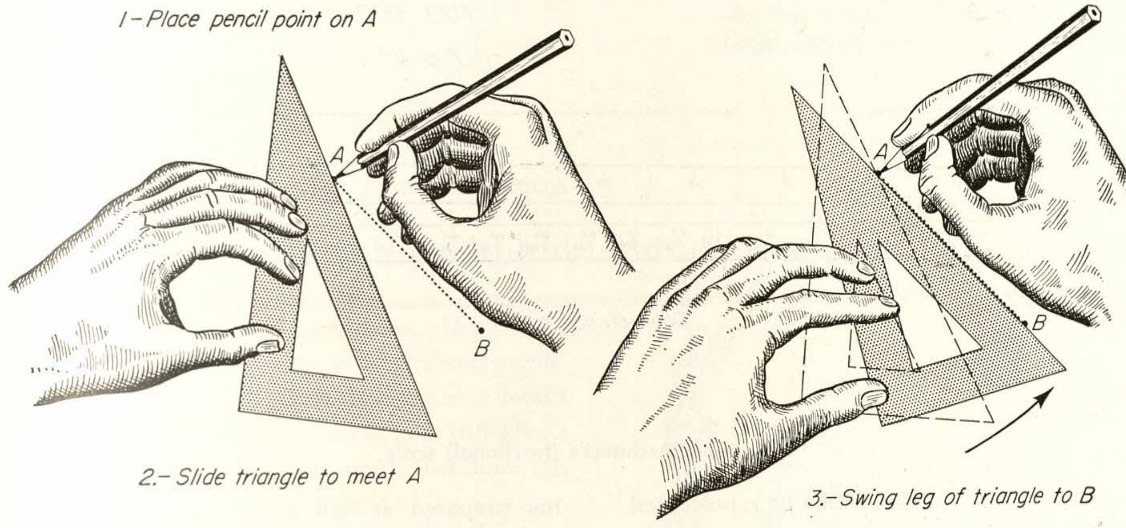

1-Place pencil point on A
A
B
2.- Slide triangle to meet A
A
B
3.-Swing leg of triangle to B

Fig. 4-13. Drawing a straight line between two points.

on the size of the object and on the size of the sheet used, the actual true-length dimensions must always be shown on the drawing sheet.

Figure 4-14 shows the architect's scale. The main divisions, or units, of the scale represent inches, and these are divided into 16 subunits representing sixteenths of an inch. In order to mark off $\frac{1}{32}$ or $\frac{1}{64}$ in., the sixteenth is halved or quartered by eye. To lay off a measurement, place the initial mark 0 at the extremity of a line, and scale toward the desired dimension. Be sure that the eye is directly over the scale. The desired dimension is indicated by an extremely light dot or a short dash drawn in a vertical direction from the edge of the scale. Greater accuracy can be obtained by taking the distance between the open points of a pair of dividers and transferring it to the sheet by lightly pinpricking its location. When a series of dimensions are to be marked off on one line, the measurements should be indicated without lifting the scale, in order to avoid cumulative errors that are bound to result in moving the scale about.

It is often necessary to show an object in enlarged or reduced size. Large objects must of course

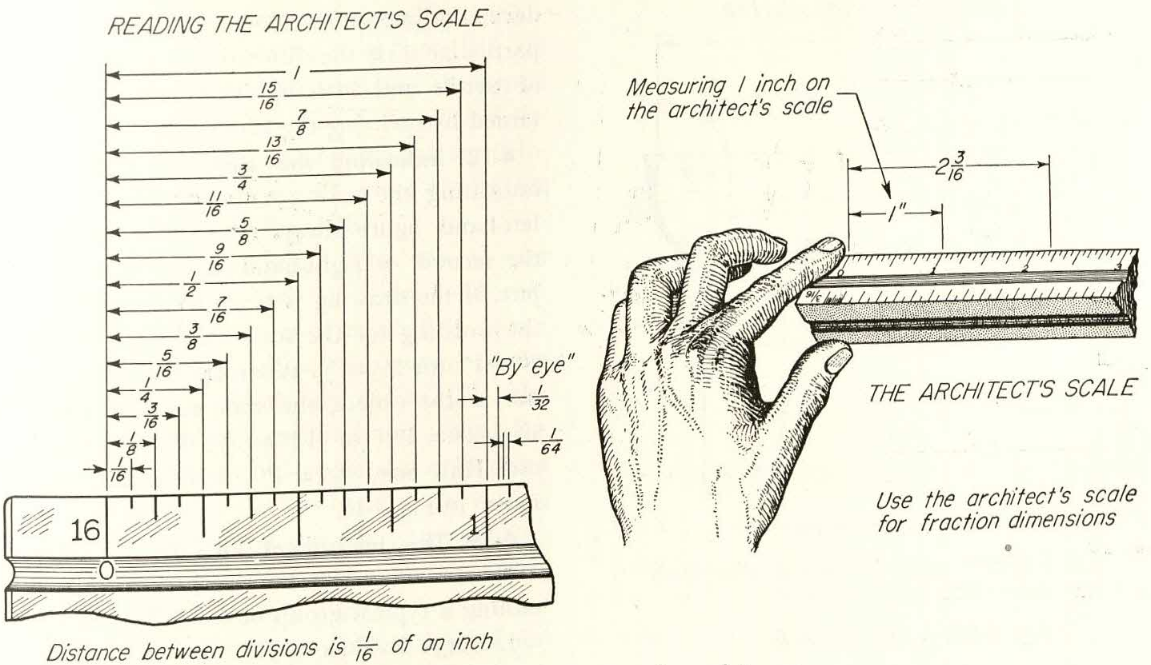

READING THE ARCHITECT'S SCALE
1
15/16
7/8
13/16
3/4
11/16
5/8
9/16
1/2
7/16
3/8
5/16
1/4
3/16
1/8
1/16
"By eye"
1/32
1/64
16
1
0
Distance between divisions is 1/16 of an inch
Measuring 1 inch on the architect's scale
2 3/16
1"
THE ARCHITECT'S SCALE
Use the architect's scale for fraction dimensions

Fig. 4-14. The architect's scale and its use.

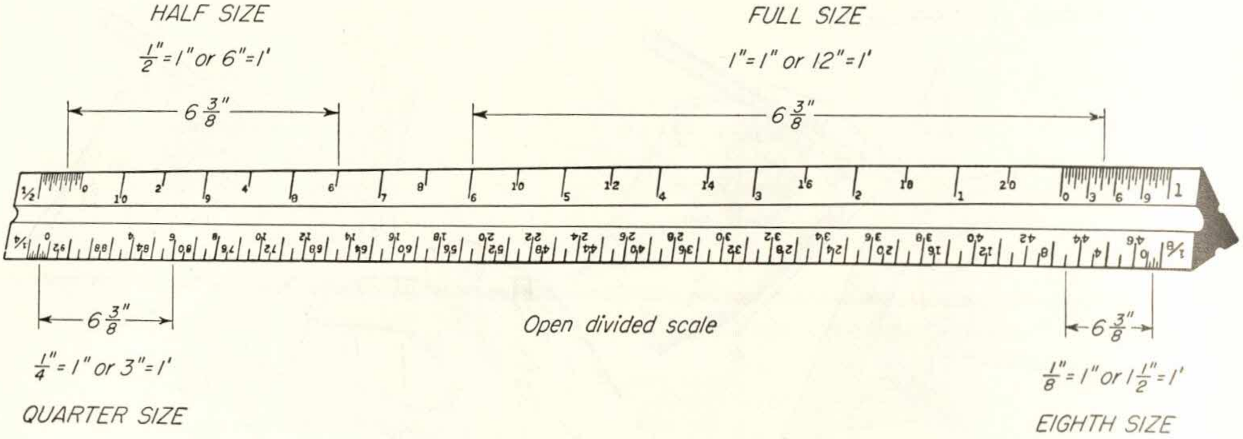


Fig. 4-15. Architect's (fractional) scale.

be reduced in scale so that they may be represented on the drawing sheet. Small pieces are usually drawn to an enlarged scale for appearance's sake or so that constructional features may be adequately represented. For an enlarged representation, double size is common; for reduction, the scales most frequently employed are half size, quarter size, and eighth size. Figure 4-15 shows an open-divided architect's scale with the various reduced scales and their relationship to the full scale. In producing a drawing at a reduced size, the desired dimensions may be read directly by referring to the proper reduced scale on the measuring stick. Suppose the dimension 6⅜ in. is desired on a drawing prepared at half scale. Referring to the left edge of the stick where the figure ½ appears, start at 0 and read toward the right along the whole-unit divisions until the figure 6 has been reached. The distance from 0 to 6 represents 6 in. at half scale. The fraction ⅜ is obtained by reading from 0 toward the left on the subdivided unit extending toward the outer extremity of the scale. The other scales are used in a like manner.

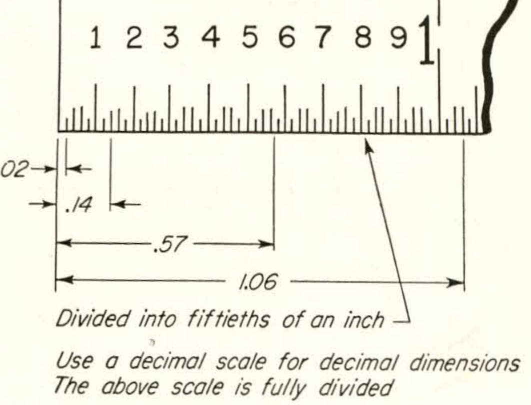

ENGINEER'S SCALE
Divided into tenths of an inch
1.2
.7
.1
ONE INCH
1 2 3 4 5 6 7 8 9 1
.02
.14
.57
1.06
Divided into fiftieths of an inch
Use a decimal scale for decimal dimensions
The above scale is fully divided

Fig. 4-16. A decimal scale.

4-17. The decimal scale. The decimal scale is full-divided, thus making it possible to read measurements from either end of the stick. The inch units are usually divided into 10, 20, 30, 40, 50, and 60 decimal parts of an inch. The 20-part division lends itself readily to drawings prepared at half size. Figure 4-16 shows the reading of various decimal dimensions. Note especially that on this particular scale the dimensions are shown in terms of tenths and fiftieths. The hundredths are obtained by splitting the fiftieths by eye.

4-18. Indicating the scale on a drawing. In indicating the scale on the drawing, the first, or left-hand, figure always refers to the drawing, and the second, or right-hand, figure refers to the object. If the drawing is twice the size of the object, the wording for the scale may read: Double Size, 2" = 1" (or 2' = 1'). When the drawing is the same size as the object, the scale note should be: Full Size, 1" = 1" (or 12" = 1'). For reduced scales, use: Half Size, ½" = 1" (or 6" = 1'), etc., as was shown in Fig. 4-15.

4-19. The instrument kit. At the upper left corner of Fig. 4-1 is shown the instrument kit containing a typical group of tools. These are:

1. Large dividers

2. Large compass with knee joint
3. Small bow dividers
4. Small bow compass
5. Bow pen
6. Ruling pen
7. Interchangeable ruling pen used in compass leg
8. Extra leg (pencil point) for large compass
9. Container with spare parts.

On procuring a set of instruments, they should be carefully scrutinized for accuracy, balance, structural features, and finish. Checking on these details will assure the acquisition of tools that will give a lifetime of service. Good instruments cost more but they are worth the extra investment.

4-20. The compass. The compass is used to draw circles and arcs (see Fig. 4-17). Auxiliary parts include adjustable, reversible, and replaceable needle points. Separate pen and pencil legs and lengthening bars are available for instruments manufactured for this manner of conversion. The center-wheel-adjustment type, with its even tension and positive adjusting mechanism, is very useful in securing the accurate results essential to fine drafting. If desired, a small compass may be used for drawing the smaller arcs and circles.

For very small accurate circles, a specially designed instrument is used which permits the center pin to remain stationary as the pen or pencil portion rotates around the center shaft. This convenient instrument is a *drop compass* (Fig. 4-18).

The *beam compass* consists of a long bar, on the ends of which the needle point and the pencil or pen attachment may be placed. Its simple design and ease of adjustment and operation are helpful in the drawing of the very large circles for which they are intended (Fig. 4-18).

Use bow compass for circles up to 2" dia.
Large compass for circles up to 10" dia.

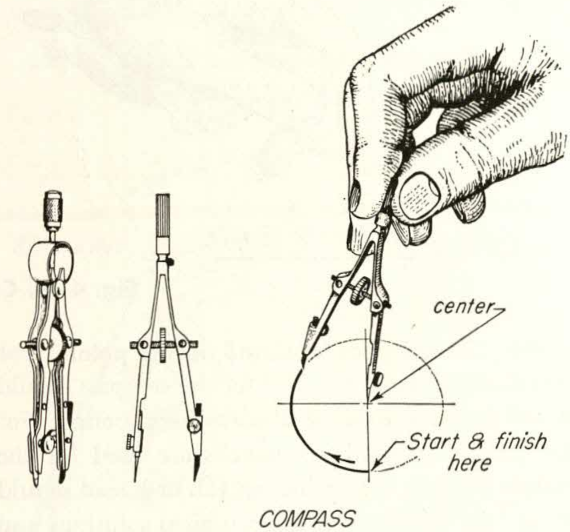


Fig. 4-17. The compass and its use.

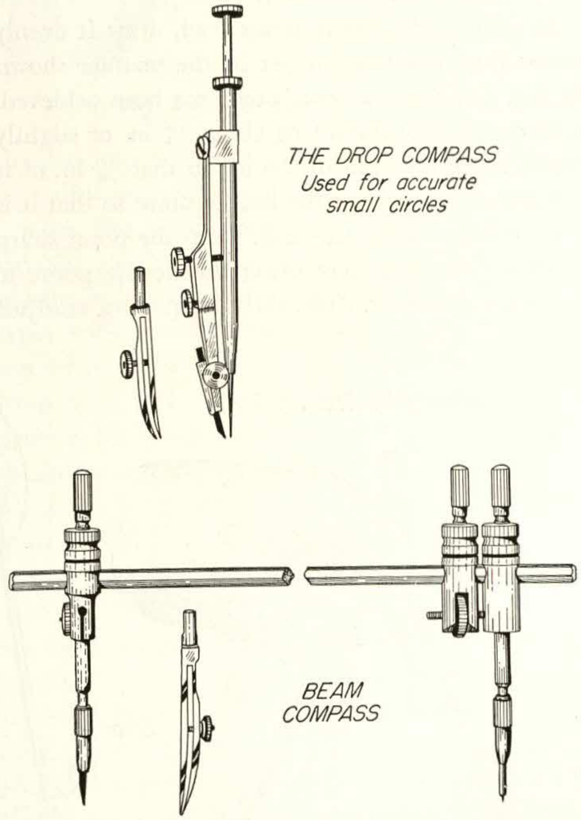


Fig. 4-18. Drop compass and beam compass.

4-21. Use of the compass. The use of the compass is illustrated in Fig. 4-17. Locate the center for the arc or circle by two very lightly drawn short intersecting lines. Adjust the opening of the legs of the compass to the desired radius. Hold the compass with the thumb and first and second fingers of the right hand, and guide the steel point with the little finger of the left hand to the center, being careful to locate the compass point exactly. Now bring the pencil point down to the paper, and, with the hand leading slightly beyond the pencil end, swing the compass with a twist of the thumb and two fingers in a clockwise direction until the arc or circle has been completed. When drawing concentric circles, draw the smallest one first.

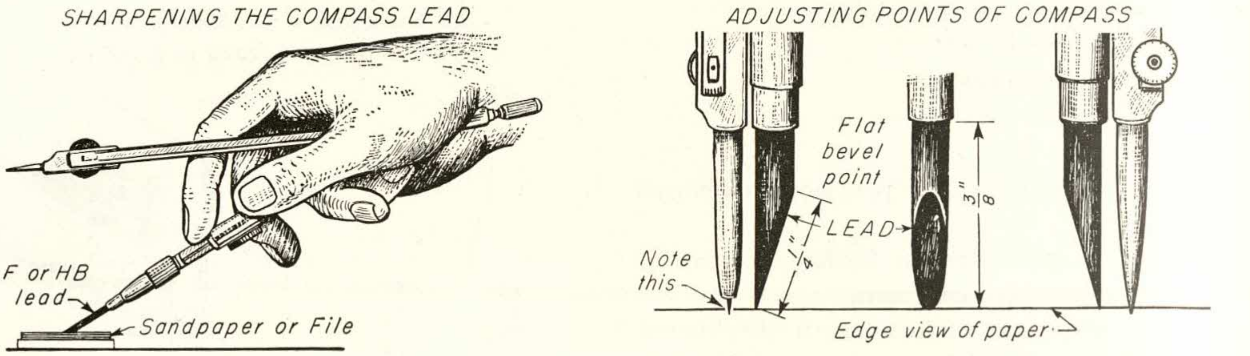


Fig. 4-19. Care of the compass.

4-22. The compass lead and needle point. For most drafting work, the lead for the compass should be softer than that of the drafting pencil. For example, if 2H and 4H pencils are used for the straight lines on a drawing, an HB or F lead should be used in the compass. In graphical solutions and design work, however, fine lines are often required and a harder lead may be necessary.

In sharpening the compass lead, draw it evenly across the file or sandpaper in the manner shown in Fig. 4-19 until a bevel point has been achieved. The cut surface should be about $\frac{1}{4}$ in. or slightly more. Place the lead in the leg so that $\frac{3}{8}$ in. of it is exposed, and adjust the needle point so that it is a trifle longer than the lead. Keep the point sharp since a dull lead may cause the needle point to slip from its center. After each sharpening, readjust the lead with relation to the needle point, since a compass out of balance will also cause the needle point to slip. The accuracy of a compass may be tested by closing it and checking to see whether or not the points meet. If they do not, the instrument should be adjusted or a new one obtained.

4-23. The dividers. Dividers are made in three basic styles (see Fig. 4-20). The plain type has two solid legs. More useful are the hairspring dividers, which have a spring attached to one of the legs that permits the regulation of minute variations in the distances between points by a slight turn of the adjusting screw. The third type is the bow dividers, which, like the bow compass, are equipped with either a center or a side wheel that permits fine adjustments. The bow type is particularly useful in very exacting work because the wheel adjust-

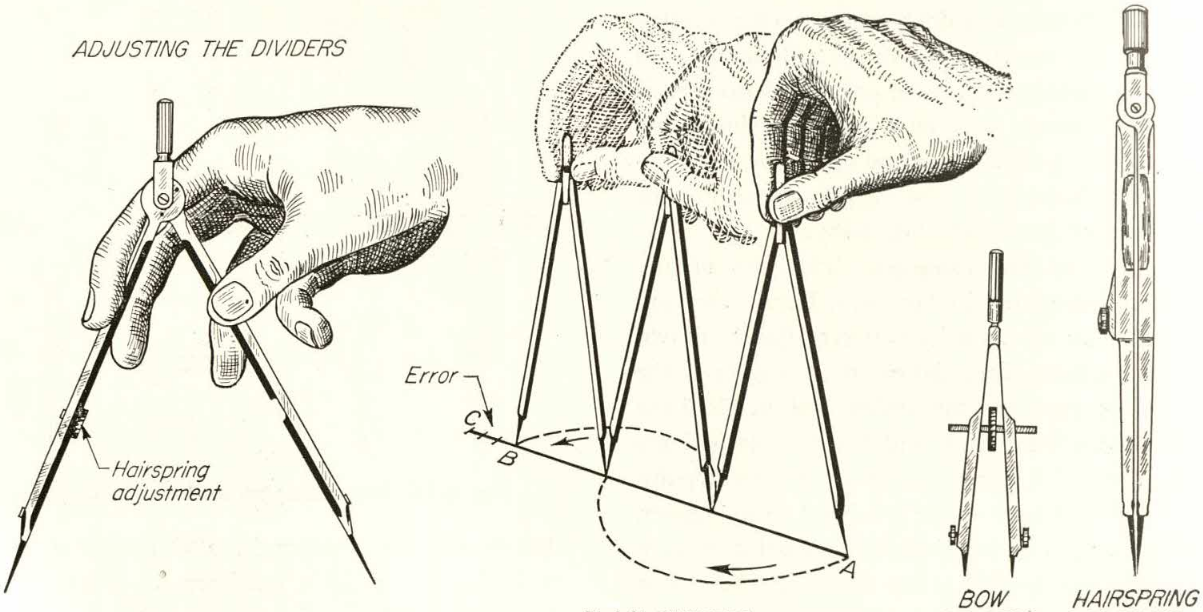


Fig. 4-20. Using the dividers.

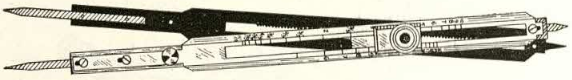
ment effectively holds the setting and therefore there is little danger of error through inadvertent spreading or contracting of the points. Some dividers have fixed needles; others are designed with adjustable, reversible, and replaceable needle points.

4-24. Use of the dividers. Dividers are used to measure or set off given distances, to divide curved or straight lines, and to transfer measurements. Before using the dividers, see that all attachments are secure, and adjust the screw in the yoke at the top of the instrument to give enough friction—not too loose or too tight—to permit easy one-hand manipulation. By holding one leg in the grip of the thumb and third finger and the other leg by the first and second fingers (Fig. 4-20), the draftsman can easily manipulate the setting of the instrument. In closing the dividers, the second and third fingers are slipped from between the legs, while the first finger and thumb bring the legs together. Facility in handling comes through practice.

Suppose it is desired to divide a line *AB* into three equal parts (see Fig. 4-20). Open the legs to a distance estimated by eye to be one-third the length of the line. Start at one extremity (point *A*), and swing the compass legs in half circles, alternately, until the other extremity has been approached. If the compass point does not fall on the end point *B*, do not lift the dividers until the error in distance (length of *BC*) has been corrected by increasing or decreasing the setting, whichever is necessary, by one-third the length of the error. Repeat the operation, beginning at point *A*, until the required setting is found. The bow dividers, with its sturdier adjustments, are recommended for work on small circles and short lines, and also where many short divisions are required.

4-25. Proportional dividers. Proportional dividers (Fig. 4-21) consist of two legs on a sliding and adjustable pivot. The instrument is provided with a scale that makes it possible to lay off measurements at a given proportion, since the distance between the points of the legs at one end bears a definite proportion to the distance between the points at the other end. When the dividers are adjusted by means of the sliding pivot, a line may be divided into any number of parts or lengthened to any given proportions, the circumference of a circle divided into any number of parts, or the diameter or radius of a circle enlarged or reduced.

PROPORTIONAL DIVIDERS



Used for copying to an enlarged or reduced scale

Fig. 4-21. Proportional dividers.

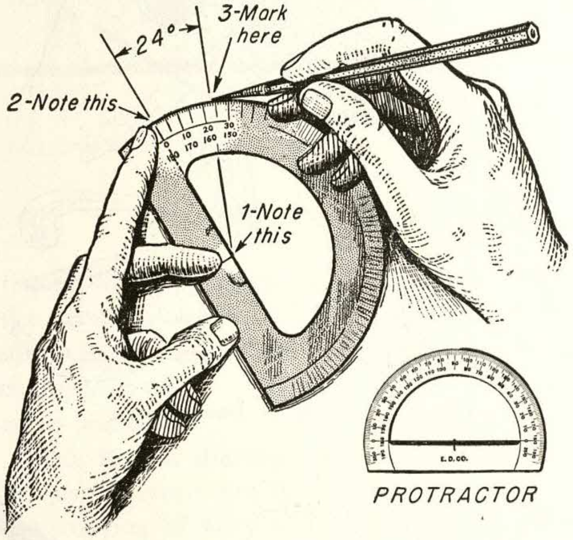


Fig. 4-22. Using the protractor.

4-26. The protractor. Protractors are semicircular in shape and are made of paper, wood, plastic, or metal. Draftsmen prefer the transparent types with beveled edges, graduated to ½ or 1°, numbered at 10° intervals, and permitting readings from both ends (Fig. 4-22). If great accuracy is desired, the tangent method of laying out an angle should be employed (see Sec. 5-18). For most drafting procedures, however, the use of the protractor is acceptable.

4-27. Use of the protractor. The protractor is used for measuring or setting off angles that cannot be obtained by manipulating the triangles. Suppose it is desired to draw a line making an angle of 24° with a given line. Place the vertex indicator at the spot on the line where the vertex of the required angle is to be located (follow second finger in the illustration). Align the zero indicator with the line that is given (first finger in illustration), and read the figure 24° along the beveled rim of the instrument (at pencil point). Mark this point very lightly; then draw a line through the point and the vertex. The angle thus

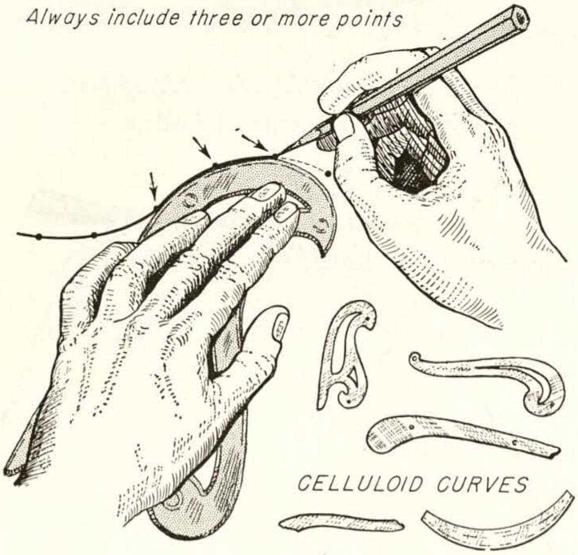

Always include three or more points
CELLULOID CURVES

Fig. 4-23. Using the french curve.

formed equals 24°. To measure an angle with the protractor, place the vertex indicator on the vertex of the angle, align one of the lines of the angle with the zero mark on the rim, and read the angle where the other line appears to cross the rim.

4-28. Irregular curves. Curved lines other than circles and circle arcs may be drawn uniformly and accurately with the help of irregular curves like the french curves (Fig. 4-23) or by means of adjustable curves and splines (Fig. 4-24). Irregular curves are generally made of a transparent material with a highly polished surface. The edges are portions of the ellipse, parabola, hyperbola, and other geometric curves. Some irregular curves are developed as radii of different sizes of circular arcs. An acceptable "fair" curve can be secured with these tools when three or more points have been plotted for the drawing of each segment of the entire line.

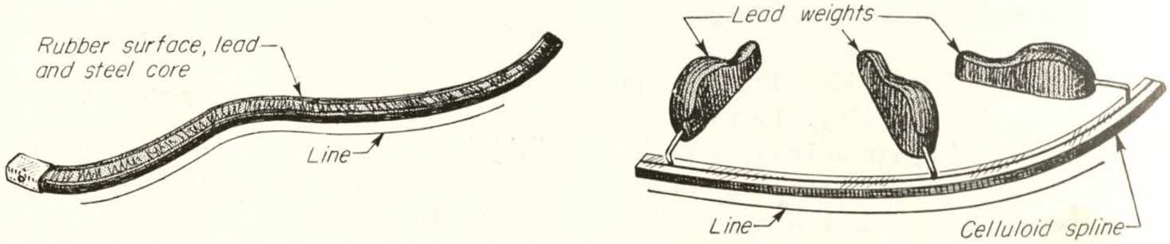


Fig. 4-24. Adjustable curve and spline.

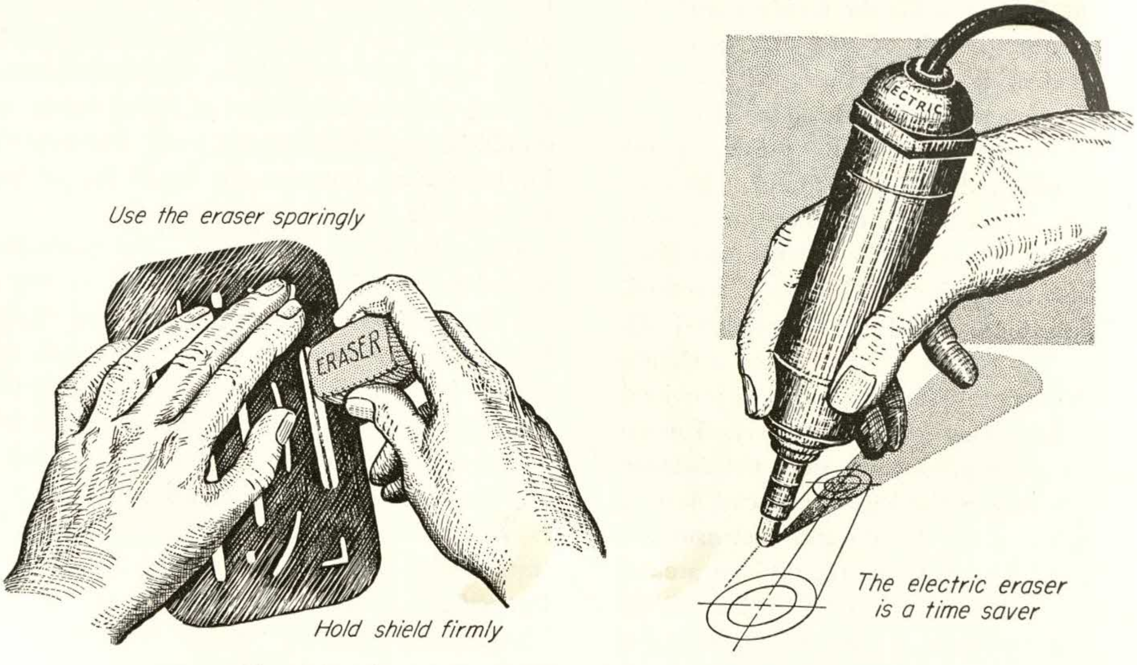


Fig. 4-25. The erasing shield and the electric erasing machine.

4-29. Erasing procedures. Care must be used in selecting erasers that will remove the pencil or ink lines without damaging the surface of the drawing sheet. A soft rubber or Artgum eraser will accomplish practically all required erasing work. The author has found the kneaded eraser superior to all others. This is a type of eraser used by artists. It is made of dough rubber, is kneadable in the hand, and has the advantage of leaving little refuse on the paper to be brushed off following erasures. The use of gritty ink erasers and the removal of lines with a knife blade are never to be recommended because both devices tend to destroy the smooth surface of the drawing paper, tracing paper, or tracing cloth. Light pencil lines are removable from tracing cloth and the better grade of tracing papers by gentle rubbing with a soft cloth dipped in benzene or carbon tetrachloride. Trial on a scrap piece of similar drawing paper or cloth is advisable.

The erasing shield is a very convenient device for erasing unwanted lines while protecting others (see Fig. 4-25). It also prevents wrinkling the paper and the possibility of undue damage to the surface. Although the thin spring-steel types of erasing shields remain flat over a longer period, the hard-rolled nickel-alloy shields have the advantage of being practically rustproof.

The electric eraser (Fig. 4-25) is a common tool in many commercial drafting rooms. One hand only is necessary for starting the motor, the erasing procedure, and stopping the motor. With a little practice, accuracy and satisfactory control of the instrument can be developed. The machines come equipped with interchangeable pencil and ink eraser points.

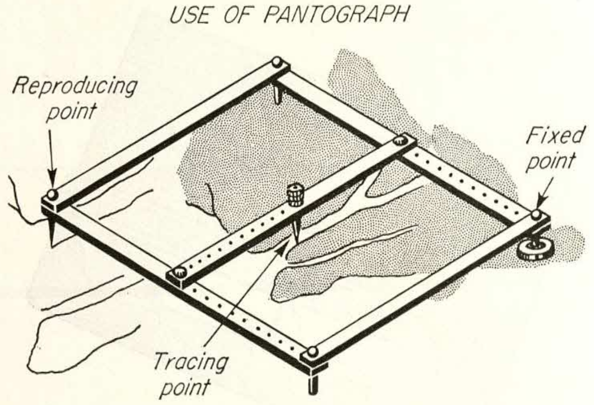


Fig. 4-26. A pantograph.

4-30. Special drafting aids. The pantograph is a useful instrument that aids in the quick and easy copying of maps and other drawings to an enlarged or reduced scale, according to a ratio selected by the operator (see Fig. 4-26). Pantographs are designed in several styles, and either wood or metal is employed in their manufacture. The tracing and pencil points are interchangeable.

Among the many special drafting aids available in the modern drafting room, the drafting machine is probably the most useful (see Fig. 4-27). The

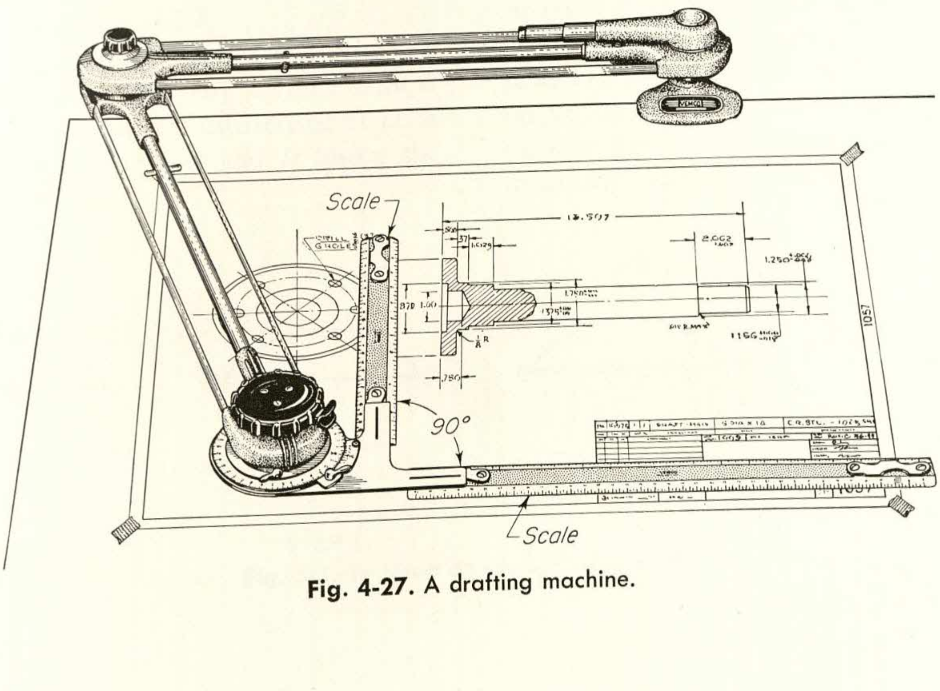


Fig. 4-27. A drafting machine.

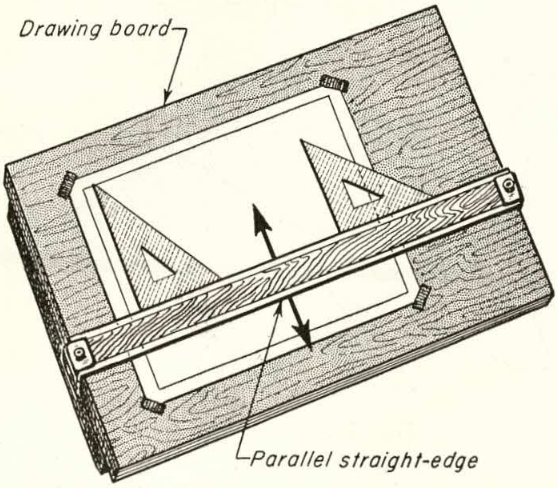


Fig. 4-28. The parallel straightedge.

use of separate T square, triangles, scale, and protractor is dispensed with, since the instruments are all combined in the drafting machine. One hand manipulates the central control to secure the proper settings while the other draws the required line. The use of fewer instruments means a considerable saving of time and effort.

The parallel straightedge, designed to perform the functions of the T square, is an instrument in which guide cords attached to the ends of the straightedge and moving along the edges of the drawing board control the device in the drawing of parallel horizontal lines. However, a triangle is still necessary for producing vertical lines (Fig. 4-28).

Other useful equipment includes many types of plastic and metal templates with stampings of the commonly used drawing constructions and symbols which can be traced directly to the drawing sheet. If a draftsman desires them, he can acquire an almost unlimited number of special drafting tools and aids to speedier and more efficient results.

Chapter 5

GEOMETRICAL CONSTRUCTIONS

Every draftsman should be familiar with the geometrical constructions that appear in this chapter. Many of them will be encountered in the working of ordinary problems, and others often occur in the solution of problems in engineering design. In working out any of the ensuing constructions where the following conditions exist, you are cautioned to note that, when a line is tangent to an arc, the tangent point is at the extremity of that radius of the arc which is perpendicular to the line. When two arcs are tangent, the line joining their centers passes through the tangent point. Always locate the tangent point before drawing the required arc.

5-1. To bisect an arc or a straight line (Fig. 5-1). Given arc *AB* and line *AB*. From the extreme points *A* and *B*, strike arcs that intersect at *C* and *D*. A line drawn through points *C* and *D* bisects the arc and the line at *F* and *E*.

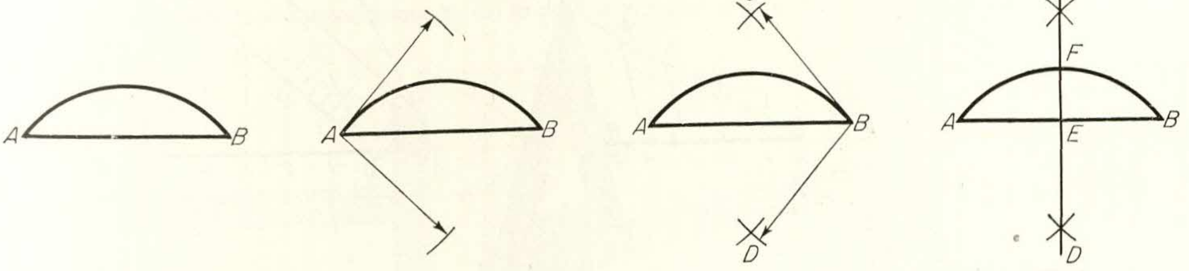
5-2. To bisect an angle (Fig. 5-2). With the vertex *A* as a center, strike any arc *BC*. With *B* and *C* as centers, strike arcs intersecting at *D*. A line drawn through points *A* and *D* bisects the angle.

5-3. To draw a perpendicular through a point to a line (Fig. 5-3). *a.* With the given point *O* as a center, strike arc *AB*. With centers *A* and *B*, strike arcs intersecting at *C*. The line through *O* and *C* is perpendicular to *AB*.

b. With the given point *O* as a center, strike arcs intersecting the line at *A* and *B*. With *A* and *B* as centers, strike arcs intersecting at *C*. The line through *C* and *O* is perpendicular to *AB*.

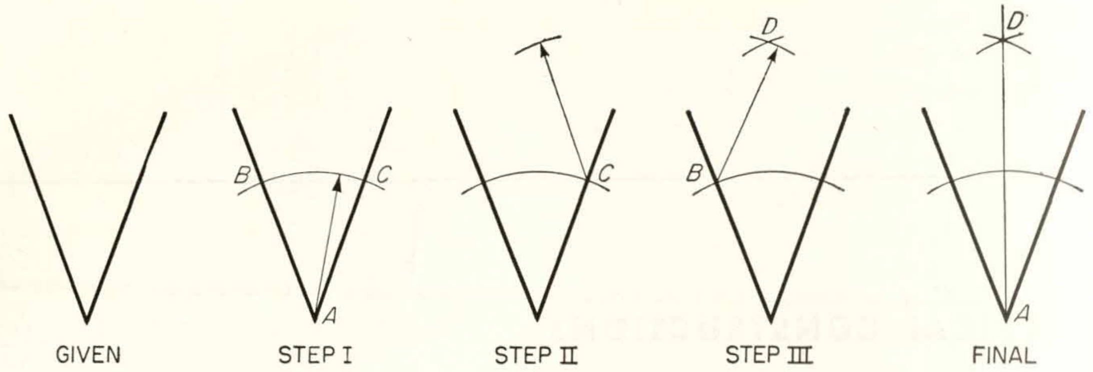
5-4. To divide a line into a given number of equal parts (Fig. 5-4). *a.* Line *AB* is to be divided into five equal parts. Through point *A*, draw any line *AC*, and scale off five equal divisions on this line. From point 5, draw line 5*B*. Through the other points, draw lines 4-4, 3-3, 2-2, and 1-1 parallel to 5*B*. The line *AB* is divided into five equal divisions by the parallel lines thus drawn.

b. Line *AB* is to be divided into five equal parts. At point *B*, erect the perpendicular *BC*. Take any evenly divided line (a scale, for instance), and place one point at *A* and the fifth division marker on *BC*. Draw the lines from points 4, 3, 2, and 1 on this line perpendicularly to *AB*. These lines divide *AB* into five equal parts.



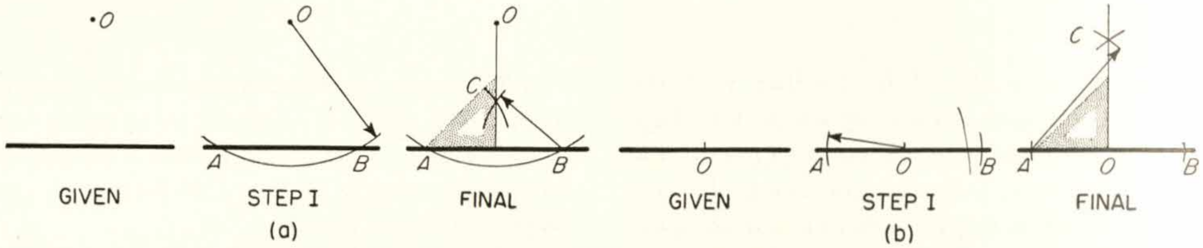
GIVEN STEP I STEP II FINAL

Fig. 5-1. To bisect an arc and straight line.



GIVEN STEP I STEP II STEP III FINAL

Fig. 5-2. To bisect an angle.



GIVEN STEP I FINAL (a) GIVEN STEP I FINAL (b)

Fig. 5-3. (*a*) Perpendicular from point to line; (*b*) perpendicular to point on line.

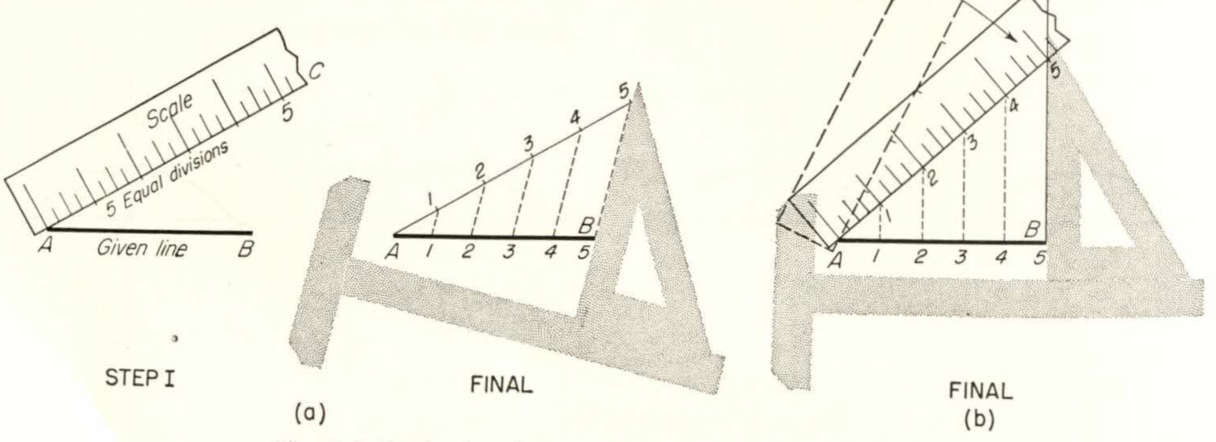
5-5. To divide a line into a given number of unequal parts (Fig. 5-5). Dividing a line into unequal parts is accomplished by using the fundamental construction explained in Sec. 5-4*a* or *b* after the desired divisions have been selected on a straightedge or scale.

5-6. To construct a square (Fig. 5-6*a*). Erect a perpendicular *AC* to *AB* at point *A*. With the length of the given side *AB* as a radius, strike the arc *BC*. With a radius equal to *AB* and with points *B* and *C* as centers, strike arcs intersecting at *D*. The points *A, B, C,* and *D* form the square.

5-7. To draw a triangle when its three sides are given (Fig. 5-6*b*). The sides *A, B,* and *C* of the triangle are given. Lay out one side equal to *A*. From its extremities, strike arcs with radii equal to *B* and *C*. The intersection of these arcs at *O* locates the required point that fixes the shape of the triangle.

5-8. To construct a regular pentagon (Fig. 5-7). The circumscribing circle is given. Bisect the radius *OA* of the circle. With *B* as a center and a radius equal to *BC,* strike arc *CD*. With *C* as a center, strike the arc *EF* passing through the point *D*. Distance *CE* or *CF* is equal to the length of one side of the pentagon. The other sides are stepped off with the dividers.

5-9. To draw a regular hexagon (Fig. 5-8). *a*.



STEP I FINAL (a) FINAL (b)

Fig. 5-4. To divide a line into any number of equal parts.

The circumscribing circle is given (marking the distance across corners of the hexagon). The radius of the circle and the length of each side of the hexagon are equal. With *A* as a center and a radius equal to *AO*, strike arc *CD*. With *B* as a center and radius *BO*, strike arc *EF*. The points *A, D, F, B, E,* and *C* indicate the lengths of the sides. Use instruments, as shown, to complete the figure.

b. If the circle is inscribed (distance across flats), the hexagon may be drawn with instruments, as shown in the figure.

c. If *AB*, the distance across corners, is given, use instruments, and draw the lines in the numbered sequence shown in the illustration to form the hexagon.

5-10. To draw a regular octagon (Fig. 5-9). *a.* Given the square, draw the diagonals *AD* and *BC*. With *C* and *D* as centers and radii equal to one-half the diagonals, strike arcs to mark points *E* and *F*. *EF* equals the length of one of the sides. Continue the procedure, and join the points.

b. The inscribed circle is given. Using the T square and 45° triangle, draw the sides of the octagon tangent to the inscribed circle.

5-11. To draw a regular polygon when one side is given (Fig. 5-10). A regular seven-sided figure is required, and side *AB* is given. Draw the semicircle *BC* with *AB* as a radius. Divide the semicircle into seven equal divisions. Draw the radial lines through point *A* and the numbered points on the arc. With point 2 as a center and a radius equal to *AB*, strike the arc intersecting line *A*3 at *D*. With *D* as a center and a radius equal to *AB*, find point *E* on *A*4. Find *F* in the same manner. Point *G* can also be found in this manner or, better, by striking the arc from point *B* across *A*6.

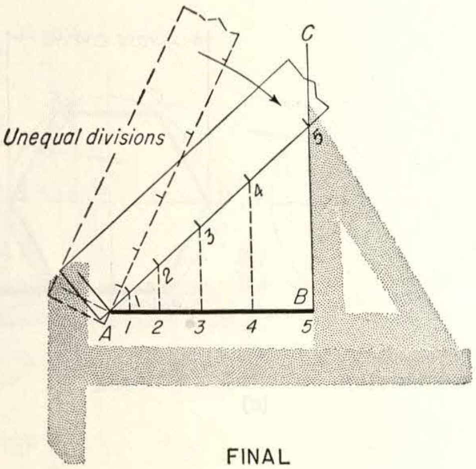


Fig. 5-5. To divide a line into unequal parts.

5-12. To draw a line through the inaccessible intersection of two lines and a given point (Fig. 5-11). The given lines and the point *P* are shown. Draw any triangle *ABP*, with one vertex through the point *P* and one on each line. Draw another triangle *CDO* at any convenient position parallel to *ABP*, with vertexes *C* and *D* on the given lines. The line through *P* and *O* is the required line.

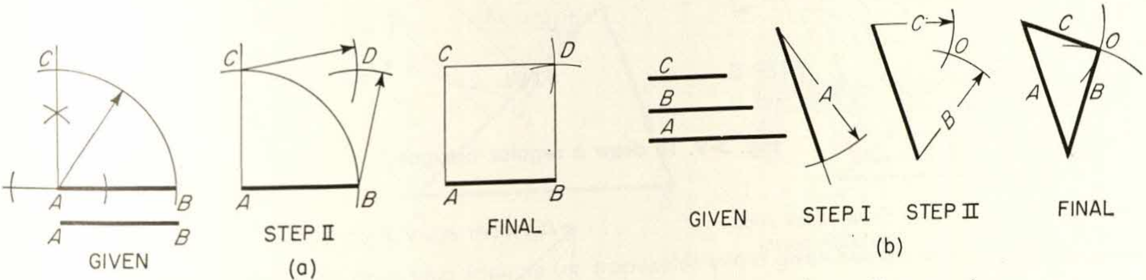


Fig. 5-6. (*a*) To draw a square; (*b*) to draw a triangle when its three sides are given.

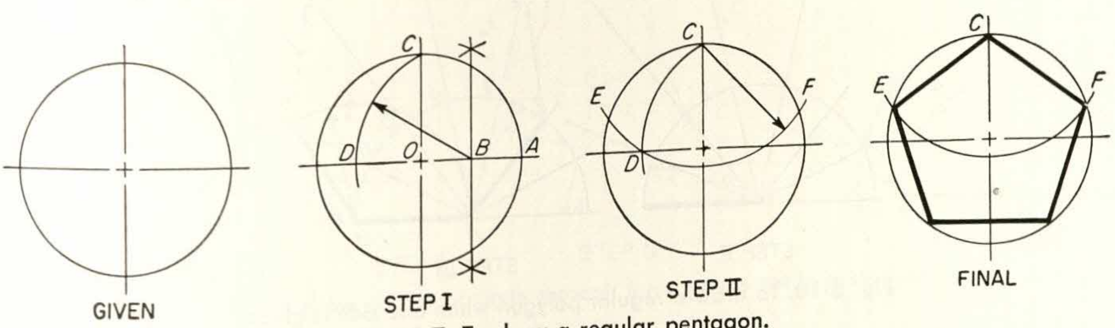


Fig. 5-7. To draw a regular pentagon.

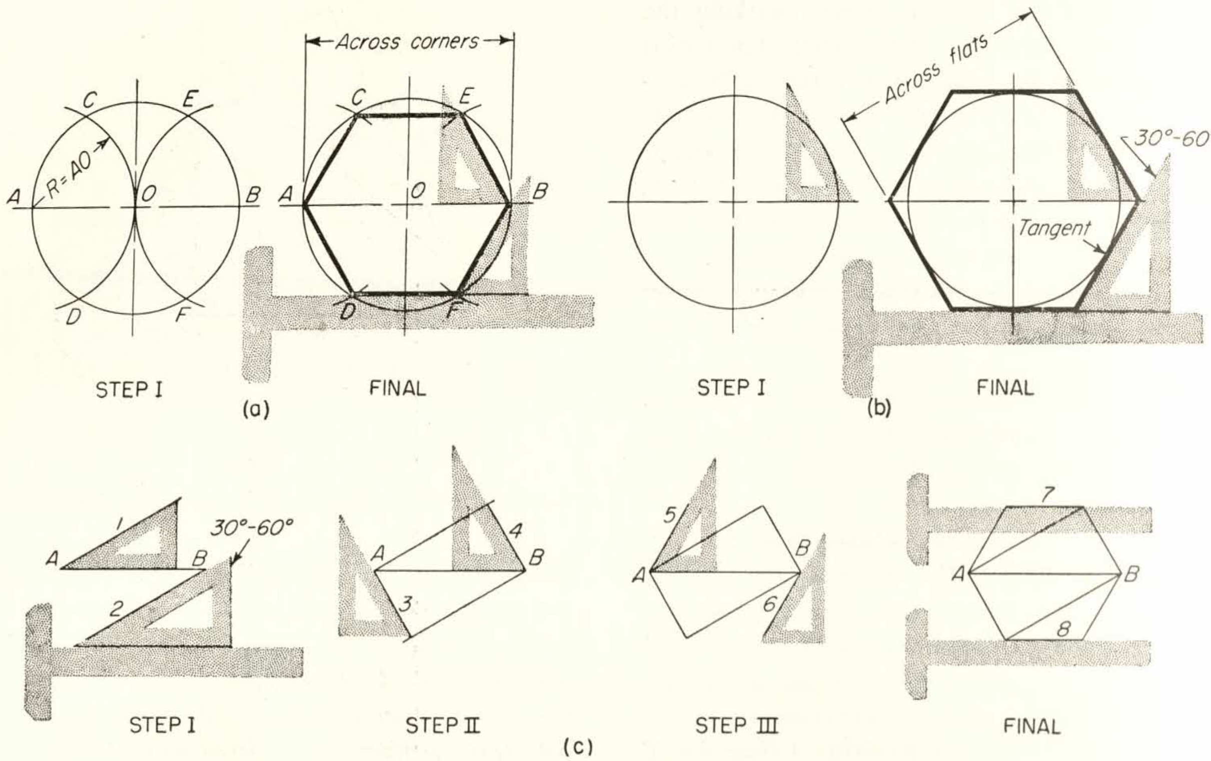


Fig. 5-8. To draw a regular hexagon.

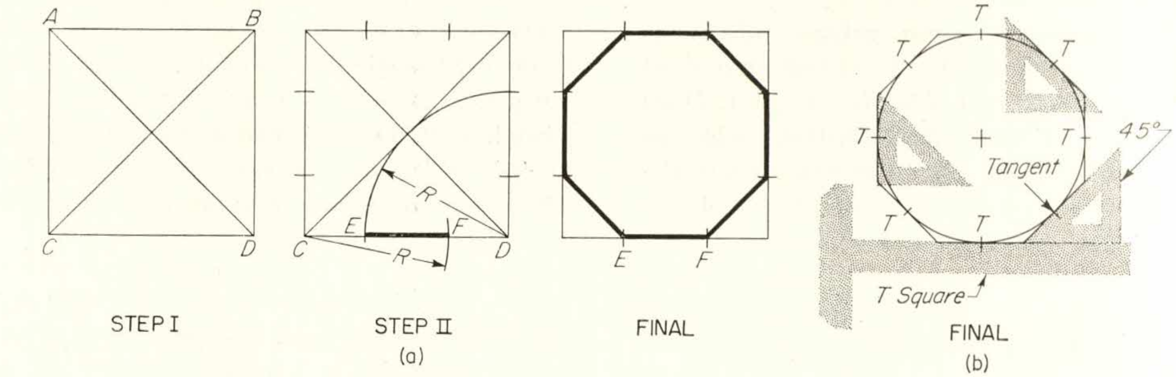


Fig. 5-9. To draw a regular octagon.

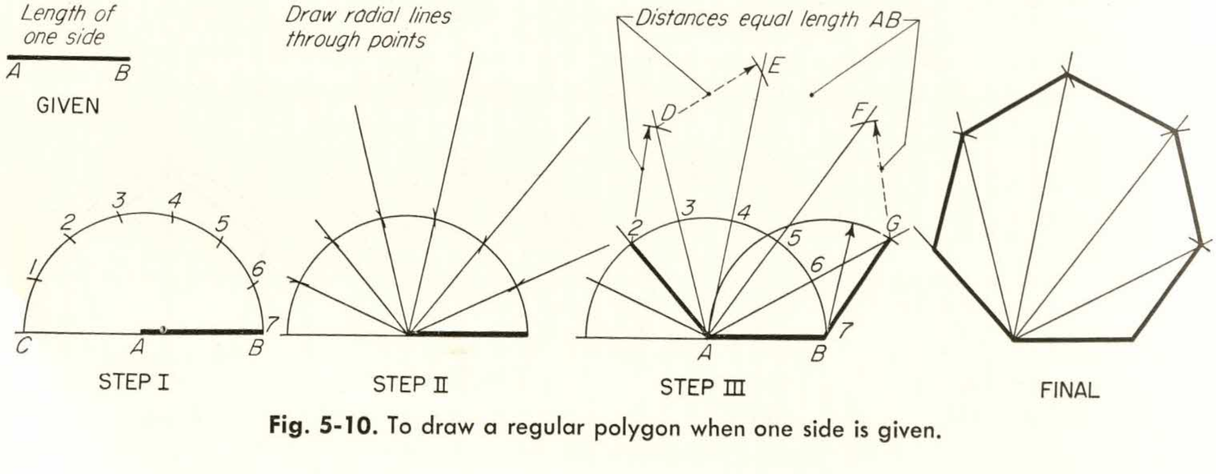


Fig. 5-10. To draw a regular polygon when one side is given.

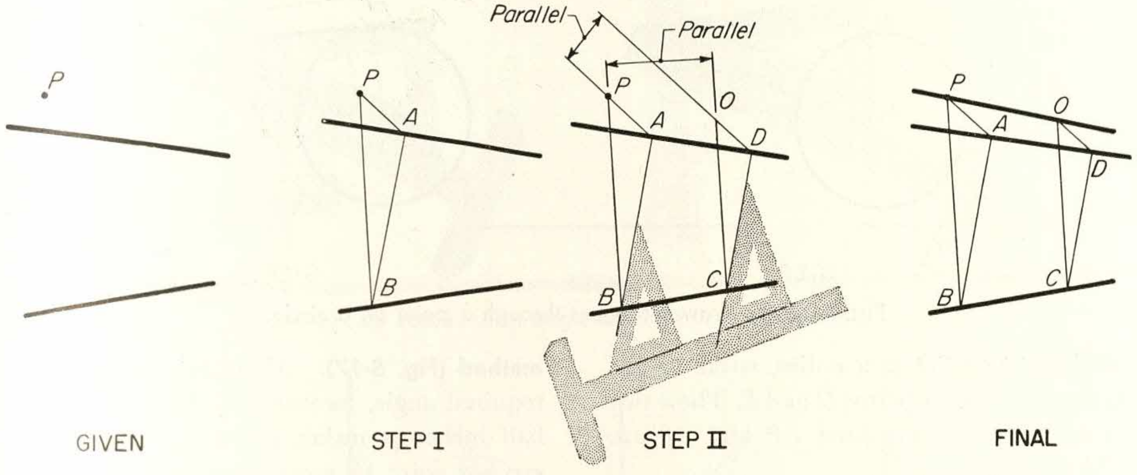


Fig. 5-11. To draw a line through a point and the inaccessible intersection of two lines.

5-13. To divide the area of any triangle (or trapezoid) into a given number of equal parts (Fig. 5-12). The triangle *ABC* is to be divided into five equal parts. Divide any side *AC* into five equal parts. Draw a semicircle as shown, with *AC* as a diameter. Draw perpendiculars from the points on *AC* to the arc. With *C* as a center, draw arcs from the points on the semicircle to intersect side *AC*. Lines drawn through the points on *AC* parallel to *AB* divide the triangle into five equal parts.

5-14. To draw a circle or an arc through three points not in a straight line (Fig. 5-13). Join the given points *A, B,* and *C* as shown. Bisect lines *AB* and *BC*. The bisectors of *AB* and *BC* intersect at *O,* which is the center for the required circle or arc. Note that *AB* and *BC* are chords of the circle.

5-15. To draw a tangent through a point on a circle (Fig. 5-14). The circle with center at *O* and the point *P* are given. Manipulate the T square and the triangle until one side passes through *P* and *O*. Then slide the triangle until the other side appears tangent to the circle at *P*. Draw the required tangent line *AB*.

5-16. To draw a tangent through a point not on a circle (Fig. 5-15). *a.* Join the center *O* and the point *P*. Bisect *OP*. Using midpoint *C* as a

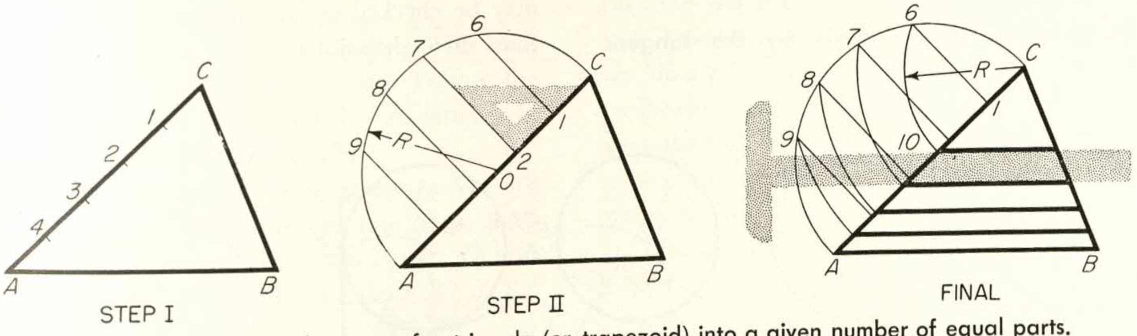


Fig. 5-12. To divide the area of a triangle (or trapezoid) into a given number of equal parts.

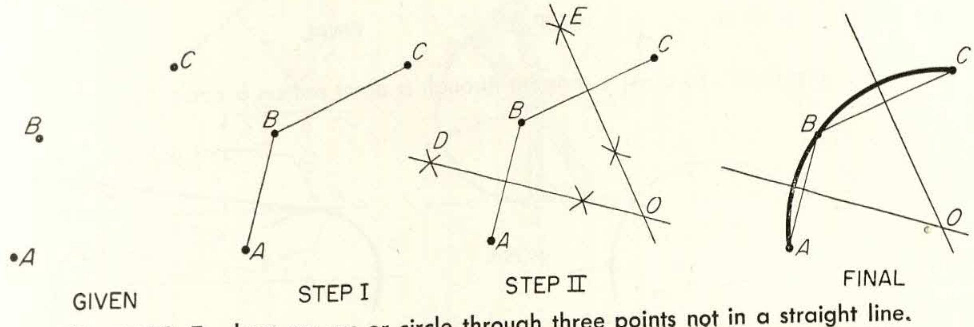


Fig. 5-13. To draw an arc or circle through three points not in a straight line.

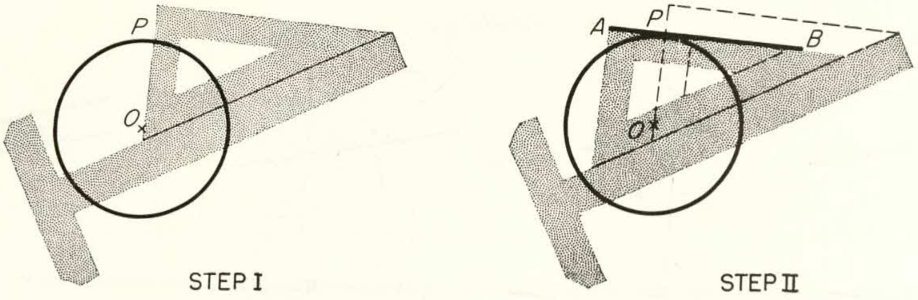


Fig. 5-14. To draw a tangent through a point on a circle.

center and distance *CO* as a radius, strike an arc intersecting the circle at points *D* and *E*. These two points indicate where the lines *DP* and *EP* are tangent to the circle.

b. Manipulate two triangles until one goes through point *P* and appears tangent (at *T*) to the circle. Then slide the top triangle to check that the center of the circle and the apparent tangent point *T* lie in the line of the other leg. Slide the top triangle to its original position to draw the tangent line *TP*.

5-17. To draw a line tangent to two circles or arcs (Fig. 5-16). Two arcs with centers at *D* and *O* are given. *A* and *B* are the radii. With *O* as a center, draw arc *C* equal to radius *B* minus radius *A*. Draw a tangent to this arc from center point *D*. Extend a line from point *O* through the tangent point *E* to *H*. Draw the required tangent line *FH* parallel to *DE*.

5-18. To construct an angle by the tangent method (Fig. 5-17). Along one side (*AB*) of the required angle, measure off 10 equal units, either half inches or inches, extending the line if necessary. At point 10, erect a perpendicular to the line *AB*. Suppose it is desired to show an angle of 33°. Look up the trigonometric function in the tangent table in the Appendix, and find the figure .649. Multiply this figure by 10 (units), and locate this distance on the perpendicular at *C*, using the decimal scale. Join points *A* and *C*. Angle *CAB* equals 33°.

5-19. To draw an arc of a given radius *R* tangent to two lines that form a right angle (Fig. 5-18). With *O* as a center and with the given radius *R*, strike the arc *AB*. With *A* and *B* as centers and with the same radius, strike the arcs intersecting at *C*. *C* is the center of the required arc tangent to the lines. The tangent points *A* and *B* may be checked by drawing perpendiculars to the lines through point *C*.

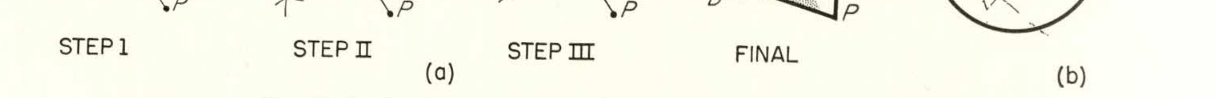


Fig. 5-15. To draw a tangent through a point not on a circle.

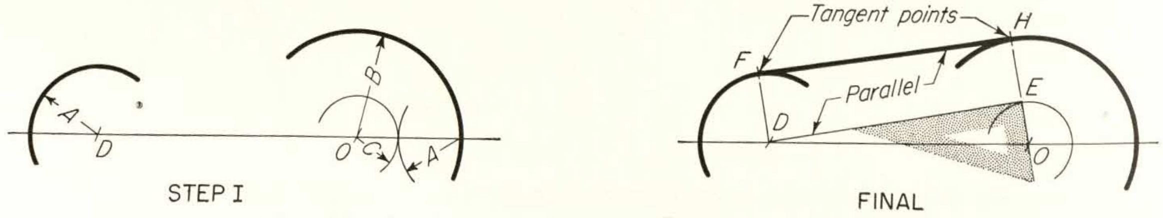
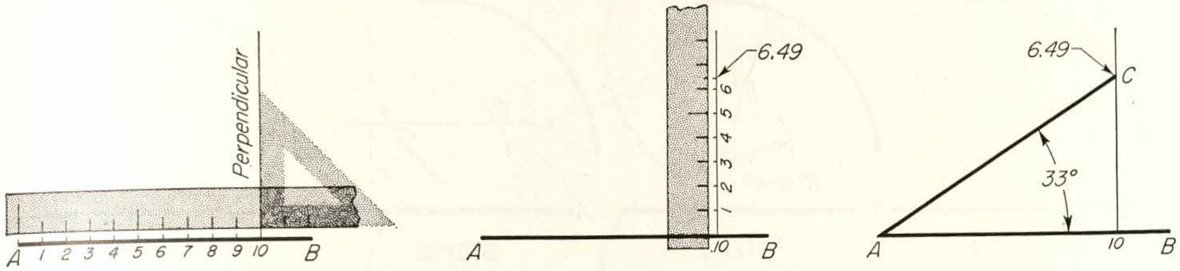


Fig. 5-16. To draw a line tangent to two arcs or circles.



STEP I STEP II FINAL

5-17. To construct an angle by the tangent method.

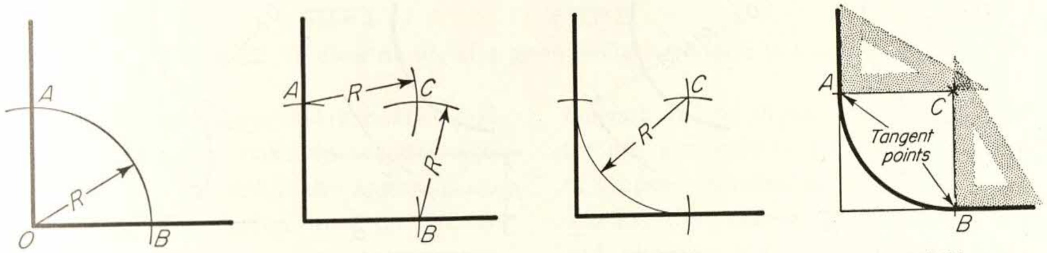


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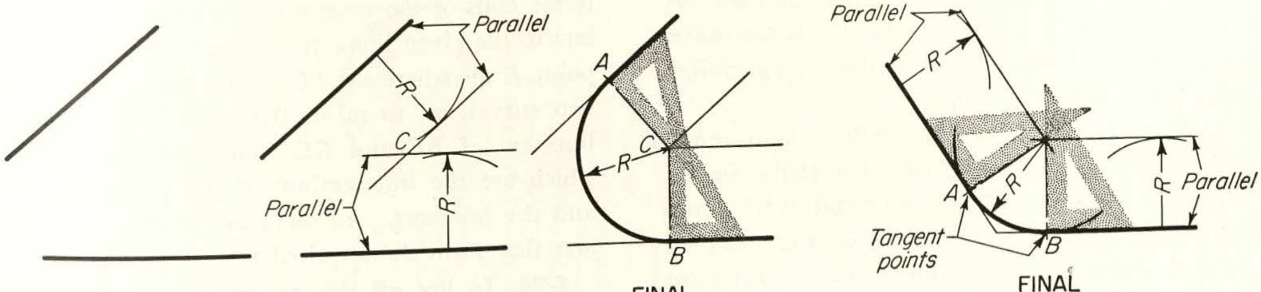
Fig. 5-18. To draw a circular arc of a given radius tangent to two lines (forming a right angle).

5-20. To draw an arc of a given radius R tangent to two lines (Fig. 5-19). *a. Lines that form an acute angle.* The lines forming the angle are given. Draw lines parallel to the given lines at a distance equal to the given radius R. These lines will intersect at the point C, which is the center for the required tangent arc. The tangent points A and B are found by drawing perpendiculars through C to the given lines.

b. Lines that form an obtuse angle. The lines that form an obtuse angle are given. Follow the identical procedure used to find the arc tangent to two lines that form an acute angle.

5-21. To draw an arc of a given radius $R2$ tangent to an arc and a straight line (Figs. 5-20 and 5-21). *a.* Given the arc with center O and radius $R1$, the line AB, and the radius $R2$ of the required arc, as shown in Fig. 5-20. With a radius equal to the arc $R1$ minus the arc $R2$ and with O as a center, strike an arc. Draw a line parallel to the given line at a distance equal to $R2$, intersecting this arc. The point C, the intersection of the line and the arc, is the center for the required arc. The line OC extended to T marks the tangent point of the arcs. The perpendicular through C to the line AB marks the tangent point on the line.

b. Given the arc with center O and radius $R1$, the line AB, and the radius $R2$ of the required arc, as shown in Fig. 5-21. With a radius equal to $R1$ plus the radius of the required arc $R2$ and with O as a center, strike an arc. Draw a line parallel to the given line AB at a distance equal to $R2$ from it. The point C, the intersection of the arc and the line, is the center for the required arc. A perpen-



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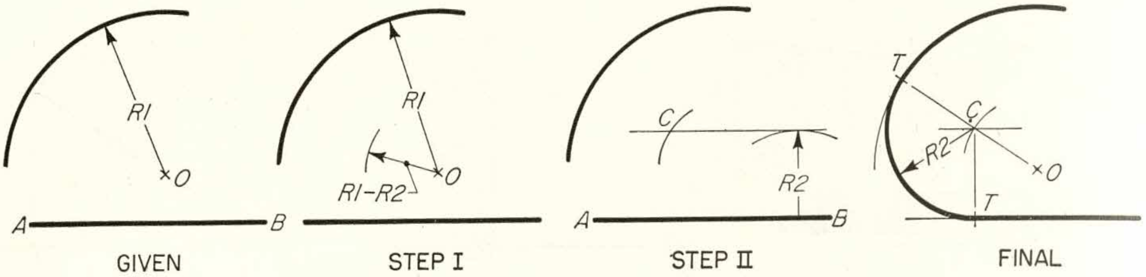
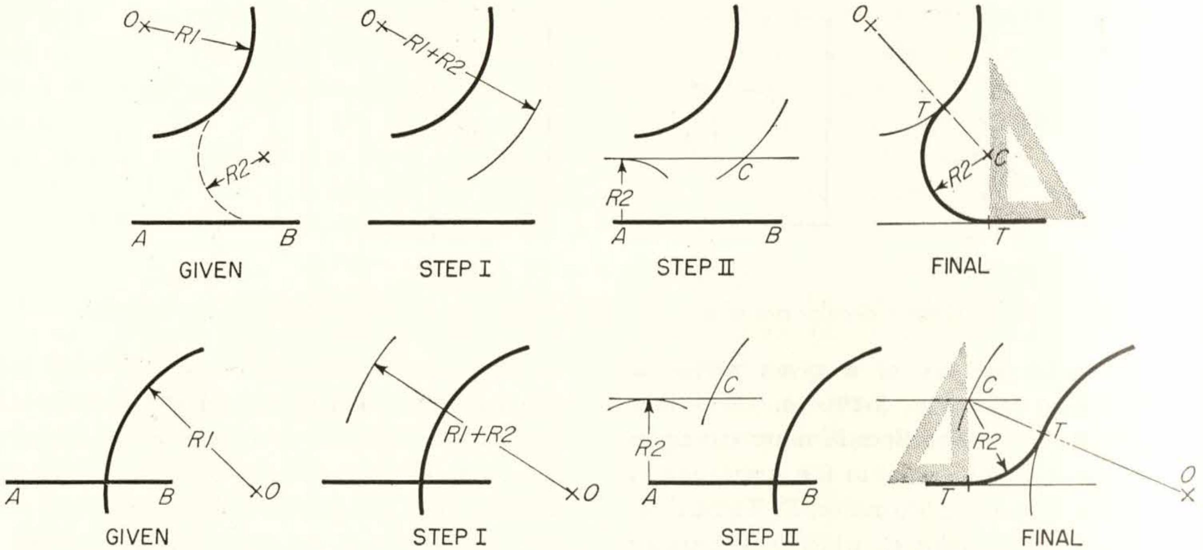
(a) (b)

Fig. 5-19. To draw a circular arc tangent to two lines (a) forming an acute angle, (b) forming an obtuse angle.



GIVEN STEP I STEP II FINAL

Fig. 5-20. To draw an arc of a given radius R_2 tangent to an arc and a straight line.



GIVEN STEP I STEP II FINAL

GIVEN STEP I STEP II FINAL

Fig. 5-21. To draw an arc of a given radius R_2 tangent to an arc and a straight line.

dicular through *C* to the line determines the tangent point on the line. Joining centers *C* and *O* determines the tangent point *T* of the arcs.

5-22. To draw an arc of a given radius *R*3 tangent to two arcs (Figs. 5-22, 5-23, and 5-24). *a.* The arcs with radii *R*1 and *R*2 and the radius of the required arc *R*3 are given, as shown in Fig. 5-22. With *B* as a center and a radius equal to *R*2 plus *R*3, strike an arc. With *A* as a center and a radius equal to *R*1 plus *R*3, strike another arc intersecting the first arc at *C*. Point *C* is the center for the required arc. To find *T*, the tangent points, join *A* with *C* and *B* with *C*.

b. As shown in Fig. 5-23, with *B* as a center and a radius equal to *R*2 plus *R*3, strike an arc. With *A* as a center and a radius equal to *R*1 minus *R*3, strike another arc intersecting the other at point *C*. Point *C* is the center for the required arc. Draw the line *CB*, and extend the line *AC* to find the tangent points *T*.

c. In Fig. 5-24, with *B* as a center and a radius equal to the *R*3 minus *R*2, strike an arc. With *A* as a center and a radius equal to *R*3 minus *R*1, strike another arc intersecting the first arc at point *C*. Point *C* is the center for the required arc. Lines joining points *A* and *B* with *C*, when extended, will locate the tangent points *T*.

5-23. To draw a reverse curve (ogee) connecting two parallel lines (Fig. 5-25). The parallel lines *AB* and *CD* are given. At *B* and *C*, the extreme ends of the reverse curve, erect perpendiculars to the given lines. Join points *B* and *C*. Select point *E* anywhere on *BC* as the point where the two curves are to meet. Draw the perpendicular bisectors of *BE* and *CE*. The points *F* and *H*, which are the intersections of the perpendiculars and the bisectors, will serve as the centers of the arcs that form the required reverse curve.

5-24. To lay off the approximate length of a circular arc on its tangent (Fig. 5-26). *a.* The arc of the circle is given. Draw the tangent *AC* through *A*. Extend the chord *AB*. Bisect the chord

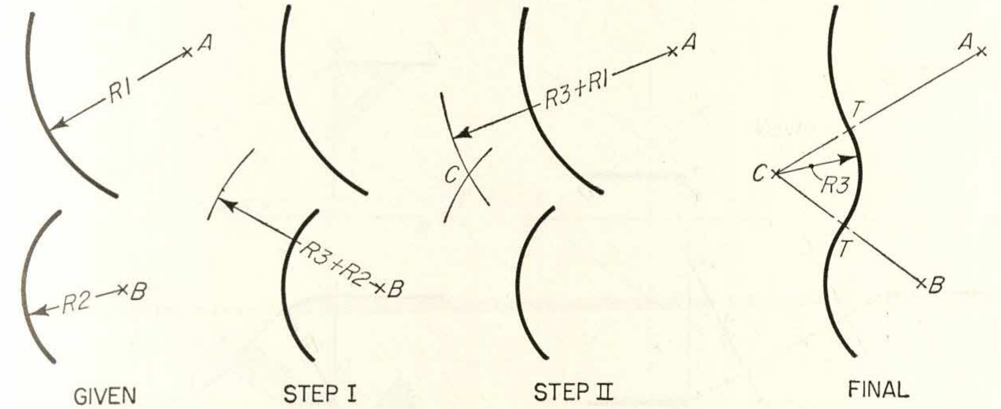


Fig. 5-22. To draw an arc of a given radius R_3 tangent to two arcs.

AB. Locate point *D* by making distance *AD* equal to *AE*. With *D* as a center, strike the arc intersecting the tangent *AC* at *H*. *AH* is the approximate length of arc *AB*, being shorter than the arc by about 6 ft to the mile when the angle between the chord and the tangent is less than 60°, down to about 5 in. to the mile when the angle reaches 30°.

b. Draw the tangent to the arc. With the dividers, step off equal distances on the arc, starting at point 5 and moving toward *T*. Step off these same distances on the tangent. The distance on the tangent will be slightly shorter than the length of the arc, a margin of error that can be disregarded in graphic representation.

5-25. The ellipse. Very frequently, inclined and oblique cylinders and holes must be represented in engineering drawings. The outline of the elliptical shapes encountered may be projected by locating points in one view and projecting them to their proper positions in the related view. This tedious procedure is not required in many practical instances, however, especially when the major and

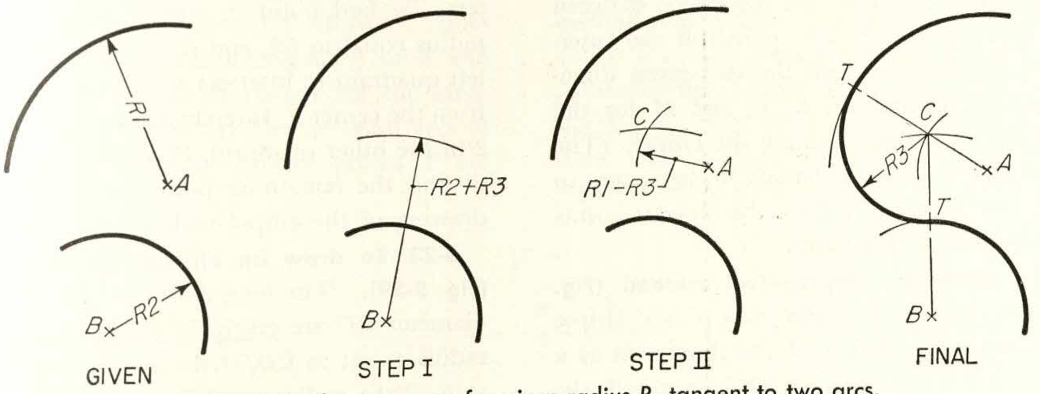


Fig. 5-23. To draw an arc of a given radius R_3 tangent to two arcs.

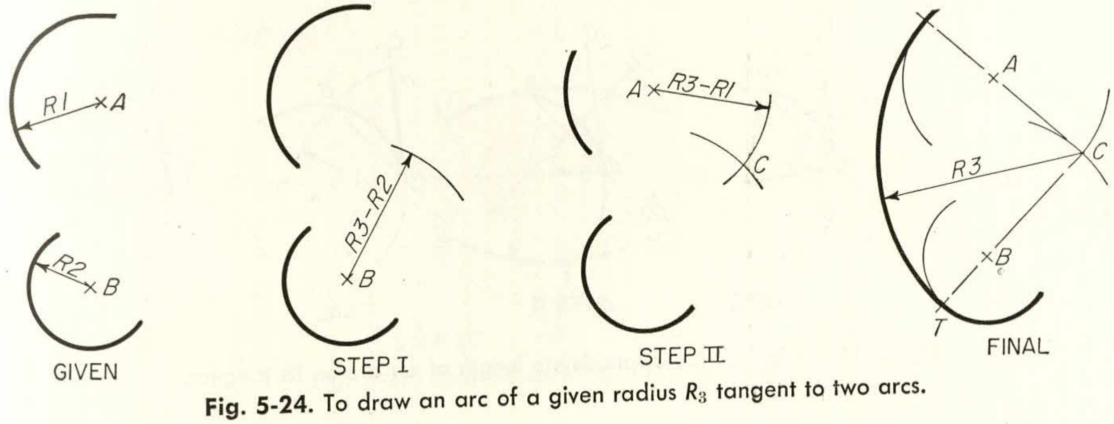
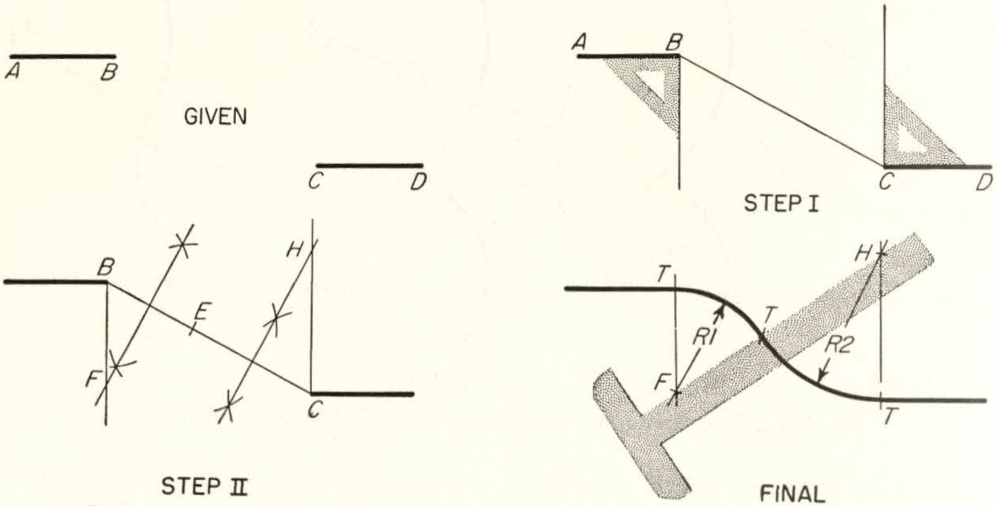


Fig. 5-24. To draw an arc of a given radius R_3 tangent to two arcs.



GIVEN STEP I STEP II FINAL

Fig. 5-25. To draw a reverse curve (ogee) connecting two parallel lines.

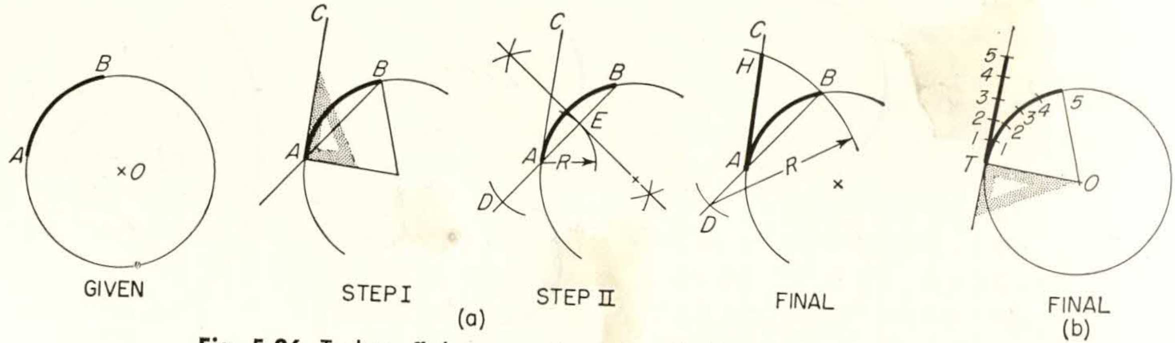
minor axes of an ellipse are known. The several methods shown in the following paragraphs are acceptable in drawing practice.

The ellipse is a conic section, the result of passing a plane through the lateral surface of a cone inclined to the base (see Fig. 16-5*b*).

5-26. To draw an ellipse—four-center method (Fig. 5-27). Join points C and A of the given long diameter CD and the short diameter AB. Lay off the distance AE equal to the difference between CO and AO. Bisect CE. The points at the intersections of the bisector with the two given diameters locate the centers H, K, L, and M for the large and the small arcs forming the ellipse. (The short diameter may be extended if necessary to find the points H and L.) Note the tangent points T for the large and small arcs.

5-27. To draw an ellipse—foci method (Fig. 5-28). The major and minor axes of the ellipse are given. With one end A of the short axis as a center and a radius equal to OC (one-half the length of the major diameter), strike arcs intersecting at E and F. These are the foci of the ellipse. Divide EO into any number of parts (the larger the ellipse, the greater the number). With point E as a center and a radius equal to distance $C1$, strike an arc in the upper left quadrant. With F as a center and a radius equal to $D1$, strike an arc to intersect the first arc. This intersection forms one point on the required ellipse. Like points are placed in the other quadrants by reversing the centers. To find point 2, take E as a center and a radius equal to $C2$, and strike an arc in the upper left quadrant to intersect an arc equal to $D2$ struck from the center F. Interchange centers to find point 2 in the other quadrant. Proceed in a like manner to find the remaining points. Then complete the drawing of the ellipse with an irregular curve.

5-28. To draw an ellipse—the Slantz method (Fig. 5-29). The long diameter AB and the short diameter CD are given. With A as a center and a radius equal to CD, strike an arc intersecting AB at E. Take a distance EF equal to two-thirds EB and mark it off on AB on both sides of its inter-



GIVEN STEP I STEP II FINAL (a) FINAL (b)

Fig. 5-26. To lay off the approximate length of an arc on its tangent.

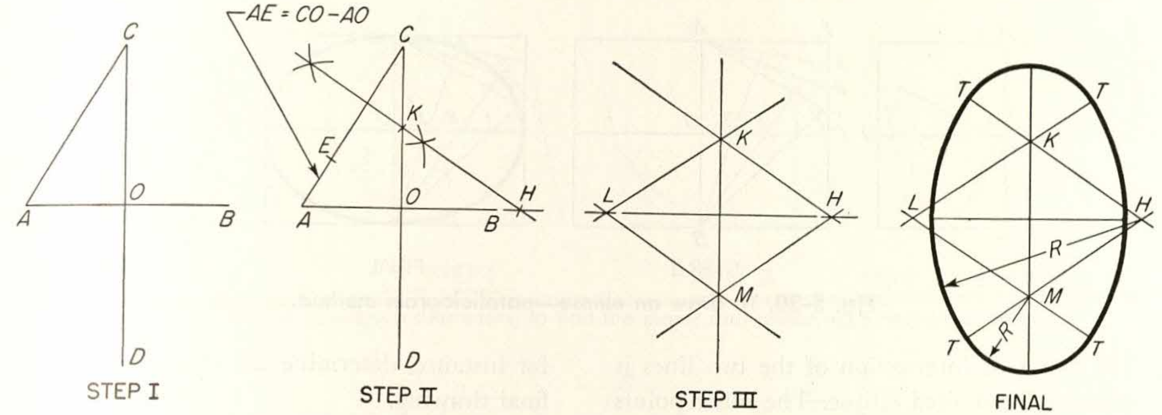


Fig. 5-27. To draw an ellipse—four-center method.

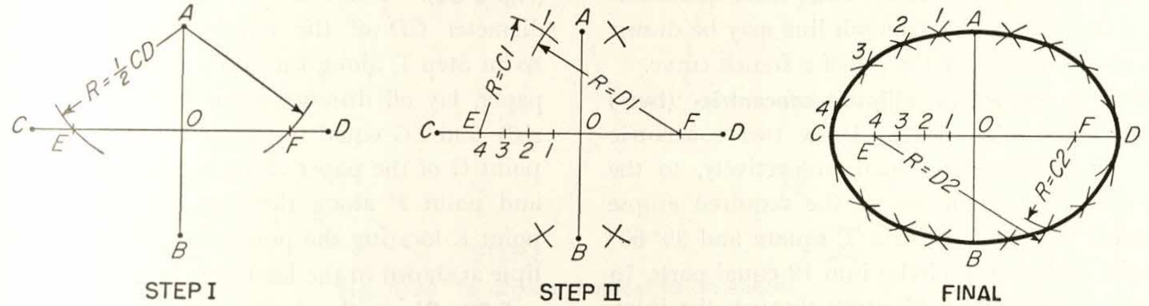


Fig. 5-28. The foci method of drawing an ellipse.

section with *CD*. These distances locate points *O* and *P*. Through points *O* and *P*, draw 60° lines intersecting *CD* (extended if necessary) at *X* and *Y*. Points *X* and *Y* serve as centers for the large arcs and *O* and *P* as centers for the small arcs of the ellipse. Note that the tangent points *T* are found on the 60° lines.

5-29. To construct an ellipse—parallelogram method (Fig. 5-30). The major (*CD*) and minor (*AB*) axes are shown in the rectangle and the parallelogram. Divide *CO* and *CE* into the same number of equal divisions, starting at *C*. From *A*, draw a line to point 3 on *CE*. From *B*, draw a line through point 3 on *CO*, intersecting the previous

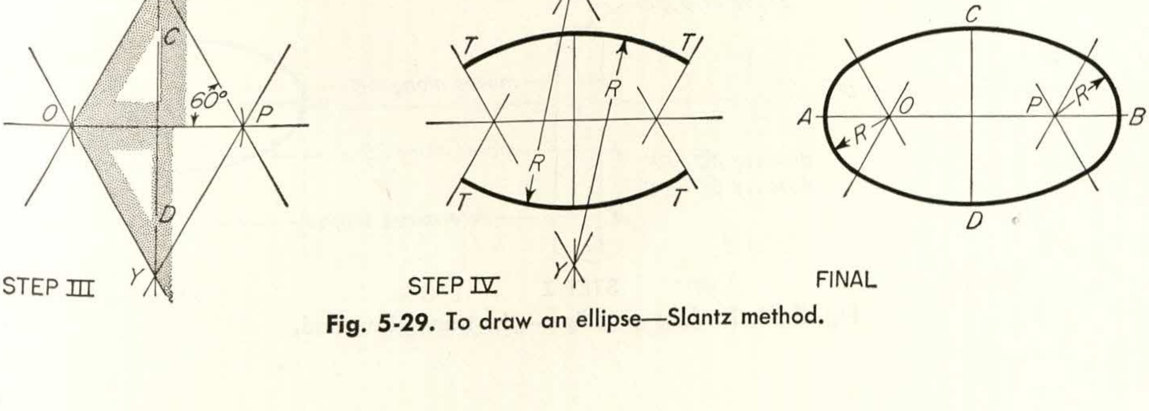


Fig. 5-29. To draw an ellipse—Slantz method.

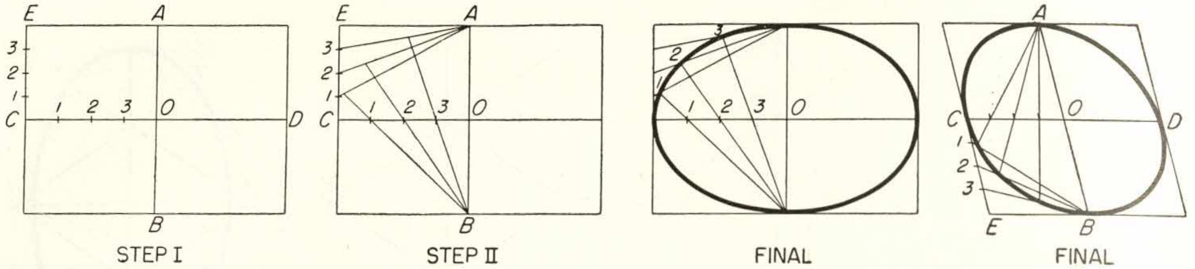


Fig. 5-30. To draw an ellipse—parallelogram method.

line. The point of intersection of the two lines is one point on the desired ellipse. The other points in that quadrant are found by following the same procedure. The points in the other three quadrants are similarly located. A smooth line may be drawn through the points by the use of a french curve.

5-30. To draw an ellipse—concentric- (two-) circle method (Fig. 5-31). Draw two concentric circles with diameters equal, respectively, to the long and short diameters of the required ellipse as shown in Step I. With a T square and 30°-60° triangle, divide both circles into 12 equal parts. In the next step, draw horizontals through the intersections of the radials and the small circle as shown at *A* and verticals at the intersections of the radials and the large circle as shown at *B*. The intersections of the verticals with the horizontals, *C*, for instance, determine the ellipse as shown in the final drawing.

5-31. To draw an ellipse—the trammel method (Fig. 5-32). The short diameter *AB* and the long diameter *CD* of the required ellipse are given. As in Step I, along the straight edge of a scrap of paper, lay off distance *EF* equal to *AO* (one-half *AB*) and *EG* equal to *CO* (one-half *CD*). Moving point *G* of the paper along the short diameter *AB* and point *F* along the long diameter *CD* finds point *E* locating the points that determine the ellipse as shown in the final drawing.

5-32. Given the conjugate diameters, to find the major and minor diameters of an ellipse (Fig. 5-33). The conjugate diameters *AB* and *CD* intersecting at *O* are given. (The diameters of an ellipse are said to be "conjugate" when each diam-

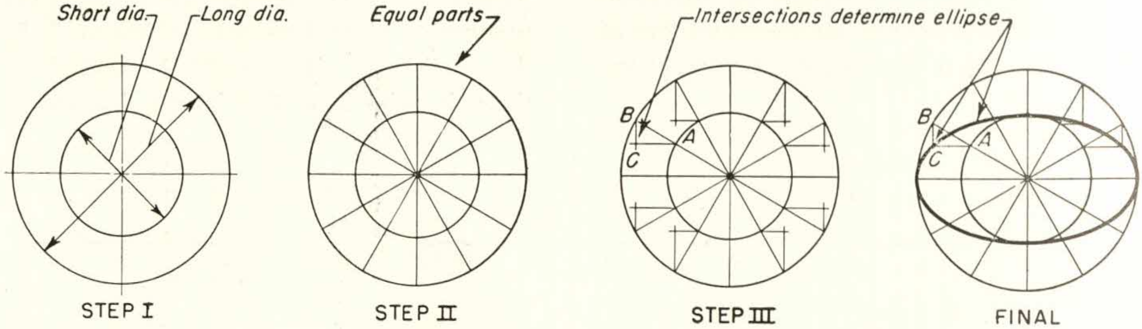


Fig. 5-31. To draw an ellipse—concentric- (two-) circle method.

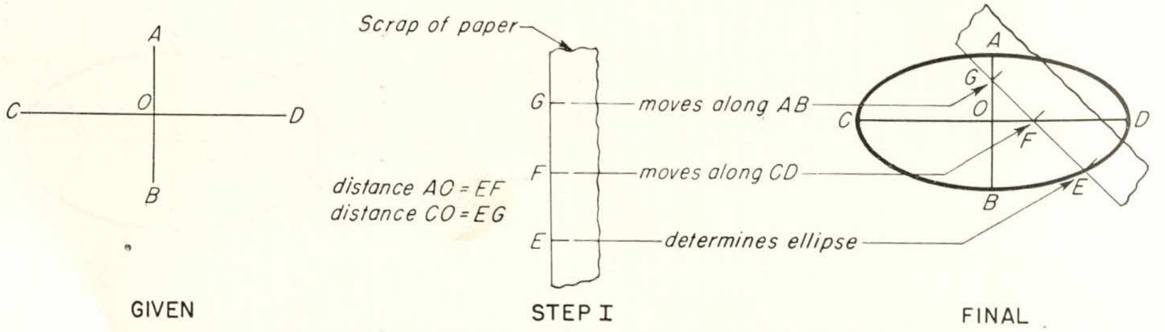


Fig. 5-32. To draw an ellipse—the trammel method.

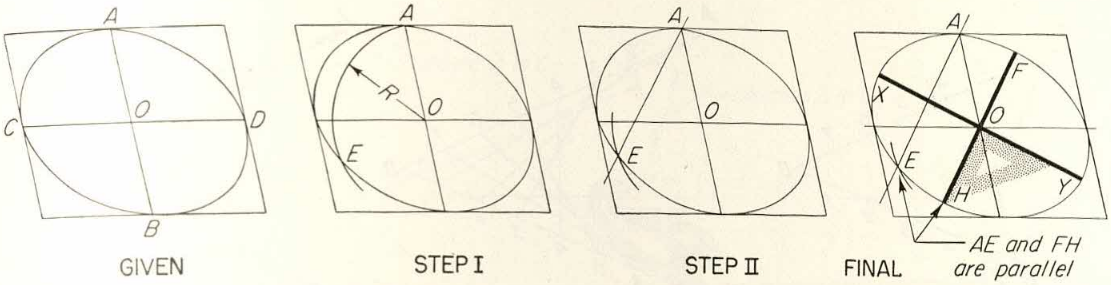


Fig. 5-33. Given the conjugate diameters, to find the major and minor diameters of an ellipse.

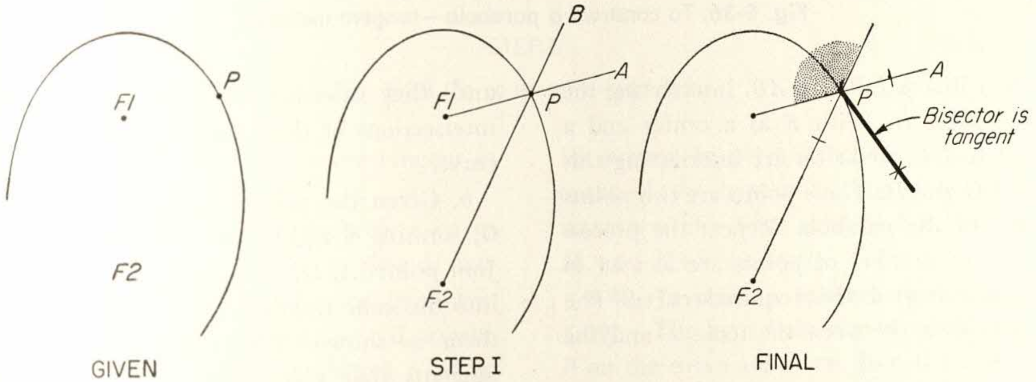


Fig. 5-34. To draw a tangent to an ellipse.

eter is parallel to the tangents drawn at the extremities of the other.) With *O* as a center and a radius equal to *AO*, strike an arc intersecting the ellipse at point *E*. Join points *A* and *E*. Through *O*, draw the line *FH* parallel to *AE*. *FH* is the minor diameter of the ellipse. The line *XY* drawn through the point *O*, perpendicular to *FH*, is the major diameter.

5-33. To draw a tangent to an ellipse (Fig. 5-34). The ellipse with its two foci, *F*1 and *F*2, and the point *P* on the ellipse are given. Join *F*1 with *P*, and extend the line to any convenient point *A*. Join *F*2 with *P*, and extend the line to point *B* anywhere outside the ellipse. Bisect the exterior angle *F*2*PA*. The bisector of the exterior angle is tangent to the ellipse at the point *P*.

5-34. The parabola. The parabola is a curve generated by a point that moves along a path equidistant from the focus (a fixed point) and the directrix (a fixed line). In geometry, it is the curved line formed by the intersection of a plane passed through a cone parallel to one of its elements. Thus, the parabola is a conic section (see Fig. 16-5*c*).

5-35. To construct a parabola (Fig. 5-35). The directrix *AB*, the axis *OE*, and the focus *F* are

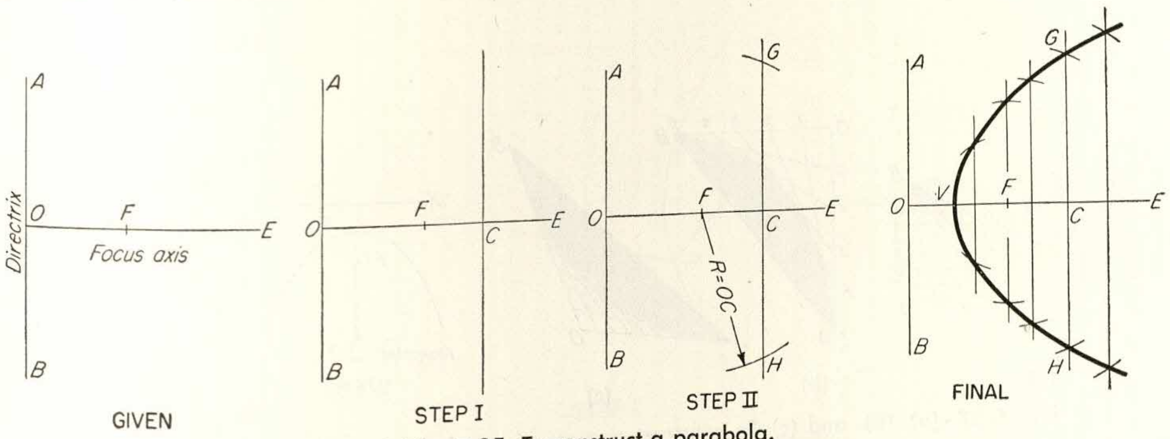


Fig. 5-35. To construct a parabola.

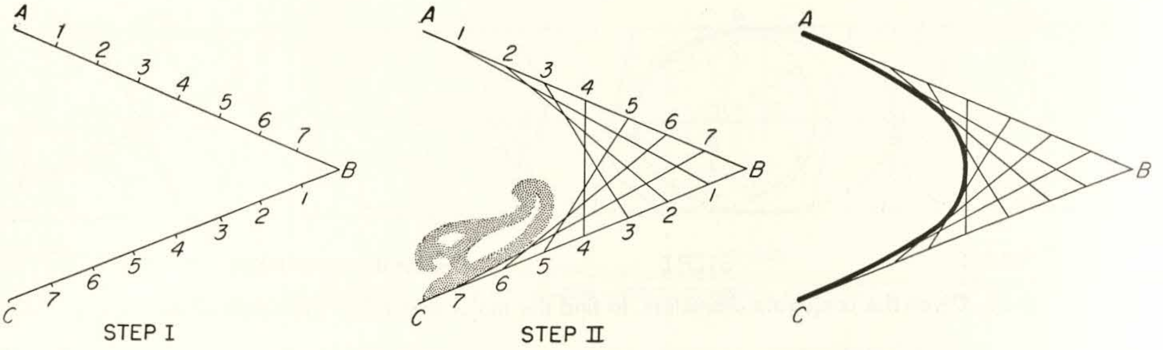


Fig. 5-36. To construct a parabola—tangent method.

given. Draw a line parallel to *AB*, intersecting the axis at any point *C*. With *F* as a center and a radius equal to *OC*, strike an arc intersecting this line at points *G* and *H*. These points are two points on the curve of the parabola. Repeat the process until a sufficient number of points are located to permit the drawing of the required curve. The vertex *V* is midway between the focus *F* and the point *O*.

5-36. To construct a parabola—tangent method (Fig. 5-36). Given the limiting points *A, B,* and *C,* which are joined as shown. The lines *AB* and *BC* are divided into an equal number of parts. Number the division points as shown. Draw lines connecting like-numbered points 1 and 1, 2 and 2, etc. These lines are tangents to the required parabolic curve. A french curve develops the contour.

5-37. To draw a parabola through two given points (Fig. 5-37). *a.* Given the points *A* and *B;* assume the point *O*. Divide distance *AO* and *BO* into the same number of equal parts. Join the point *B* with the equispaced points on *AO*. From *BO*, extend the numbered lines, parallel to *AO*, until they intersect the like-numbered lines. The intersections of these lines determine the required curve.

b. Given the points *A* and *B*, assume the point *O*, forming a right angle as shown in Fig. 5-37*b*. Join points *A, O,* and *B*. Divide line *AO* and *BO* into the same number of equal parts, and number them as shown. The intersecting lines are the tangents that give shape to the parabolic curve desired.

c. The procedure necessary to draw a parabola when the angle *AOB* is obtuse is shown in Fig. 5-37*c*. The construction is the same as in Fig. 5-37*b*. If the tangents *AO* and *BO* formed an acute angle, the same procedure as in Fig. 5-37*b* would also result in a curve of parabolic form.

d. Since the diameters of a parabola are at right angles to the directrix, a tangent to a parabola will bisect the angle between the focal radius and the diameter which passes through the point of tangency. The directrix *XY*, the focus *F*1, and a diameter *A* passing through the tangent point *P* are shown in Step I. *F*1 is joined to *P* to form the angle

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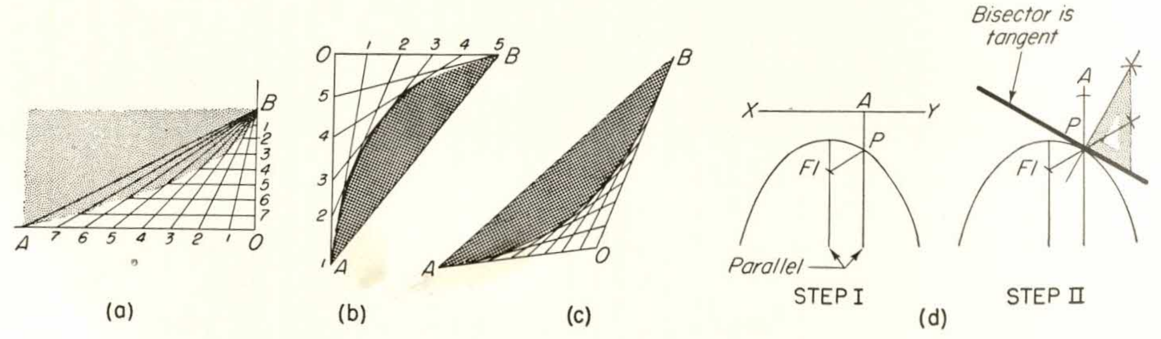


Fig. 5-37. (*a*), (*b*), and (*c*) To construct a curve of parabolic form through two given points. (*d*) To draw a tangent to a parabola.

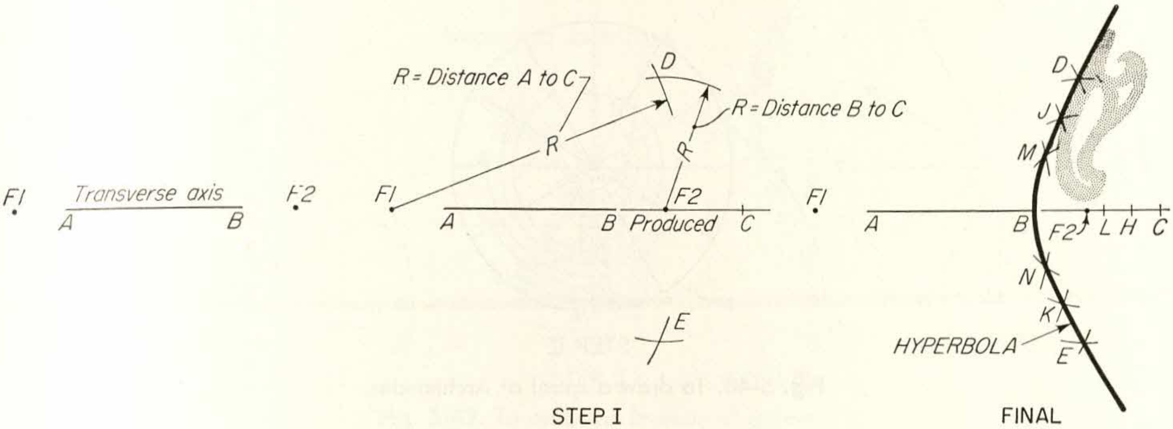


Fig. 5-38. To construct a hyperbola.

F1PA. The bisector of this angle is the tangent to the parabola at the point *P*.

5-38. The hyperbola. A hyperbola is a curve generated by a point that moves so that at any position the difference of its distance from two fixed points (foci) is a constant (equal to the transverse axis of the hyperbola). When a plane cutting a cone makes a smaller angle with the axis than any of the elements, the line of intersection between the plane and the cone is known as a hyperbola. The hyperbola is a conic section (see Fig. 16-5*d*).

5-39. To construct a hyperbola (Fig. 5-38). The transverse axis *AB* and the foci *F*1 and *F*2 are given. With *F*1 as a center and a radius (greater than *F*1*B*) equal to *AC*, strike arcs at *D* and *E*. (*C* is one of a series of points selected on *AB* extended.) With *F*2 as a center and a radius equal to *BC*, strike arcs intersecting the other arcs at points *D* and *E*. These two points are on the hyperbola. By repeating this procedure, enough points may be secured to permit the drawing of the smooth curve of the hyperbola. Points *L* and *H* on the transverse axis were used in locating points *J, K, M,* and *N* on the curve.

5-40. To draw a tangent to a hyperbola (Fig. 5-39). The hyperbola, the two foci, and the point *P* on the curve are given. Join the two foci *F*1 and *F*2 with *P*. The tangent to the hyperbola bisects the angle between the two focal radii *F*1*P* and *F*2*P*, which intersect at the point of tangency *P*.

5-41. The construction of a spiral of Archimedes (Fig. 5-40). If a point moves about a fixed point (the pole) and away from it in such a manner that its distance increases uniformly with the angle, the curve developed by its path produces a spiral of Archimedes. Start at the pole, point *O*, and lay out equal angles of, say, 30°, represented by the radial lines *O*-1, *O*-2, *O*-3, etc. On one of the radial lines, lay out equal distances representing the movement of the point. Twelve angles require twelve equal distances. Rotate the distances

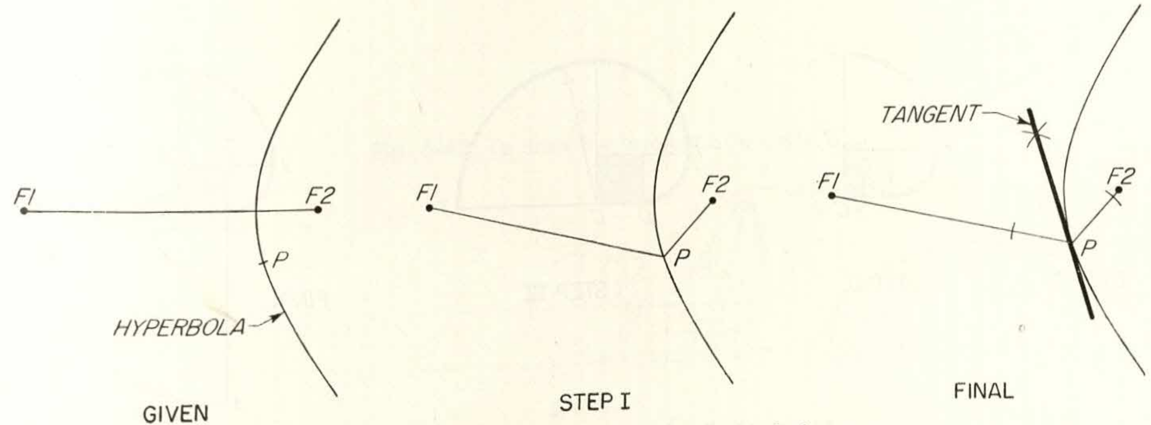


Fig. 5-39. To draw a tangent to a hyperbola.

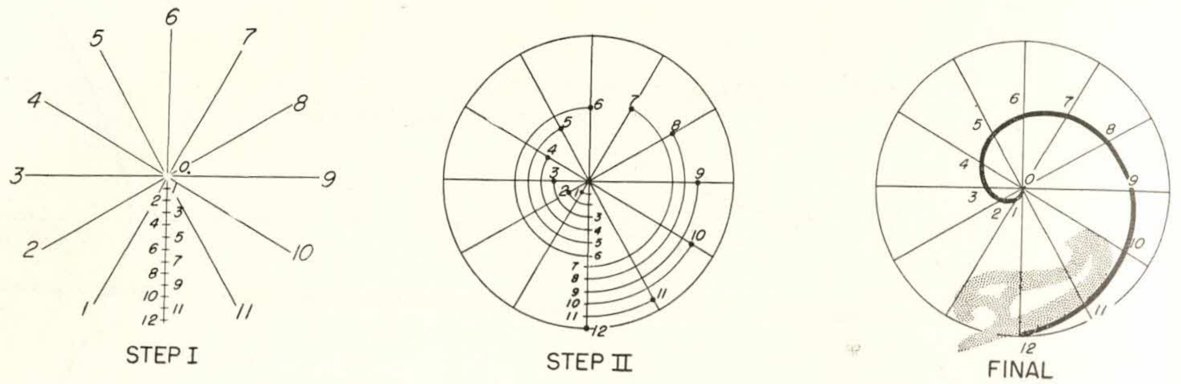


Fig. 5-40. To draw a spiral of Archimedes.

on the radial line to the corresponding position on the angle line as shown in Step II. After locating the points, use the french curve for completion of the curve.

5-42. To draw the involute of a polygon (Fig. 5-41). An involute is the path made by a point on a taut string as it unwinds from a geometric shape such as a circle or polygon. In Step I, extend the side *AB* of the polygon *ABCD*. With *A* as a center and side *AD* as a radius, strike an arc that intersects *AB* extended at 1. With *B* as a center and *B*1 as a radius, strike an arc intersecting *BC* extended at 2. Continue the procedure until all four points have been located, and then draw in the curve. The first radius is always equal to the length of the side of the polygon where the operation is started. Each succeeding arc always starts at the termination of the previously drawn arc and has a radius equal to the distance from the end of the preceding arc to the farthest extremity of the side.

5-43. To draw the involute of an arc (Fig. 5-42). The arc *AB* is given. Divide *AB* into a convenient number of parts, and number the points as shown. Draw a tangent to each division point. Mark off on each tangent the length of the corresponding arc (the distances *O*-1, *O*-2, *O*-3, etc.). A french curve will aid in securing a smooth line through the points that form the involute.

5-44. To draw the involute of a circle (Fig. 5-43). Divide the circumference of the circle into any number of equal parts. Draw the tangents to the circle at these division points. Mark off on each tangent the length of the corresponding arc, and then proceed as outlined in the preceding section.

5-45. The construction of a cycloid (Fig. 5-44). The curve generated by a point on the circumference of a circle as the circle rolls on a plane along a straight line is known as a cycloid. Given the circle (moving toward the right) and its path, line *AB*, tangent to it and equal in length to the circumference of the circle. Divide the circumference and the line into the same number of equal parts. Draw the center line *CL* parallel to *AB*. Extend the numbered points on *AB* perpendicularly to *CL*. Draw lines parallel to *AB* through the points on the circle. (These points represent successive positions of the original starting point P^0.)

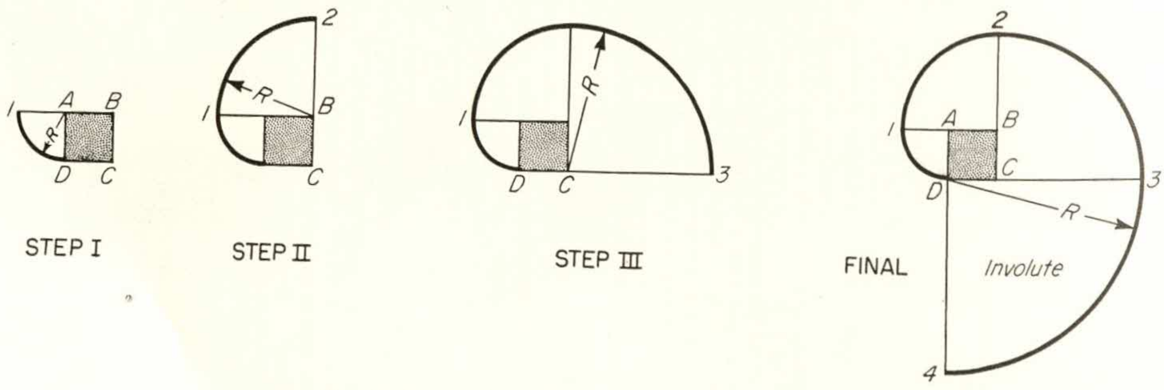


Fig. 5-41. To draw the involute of a polygon.

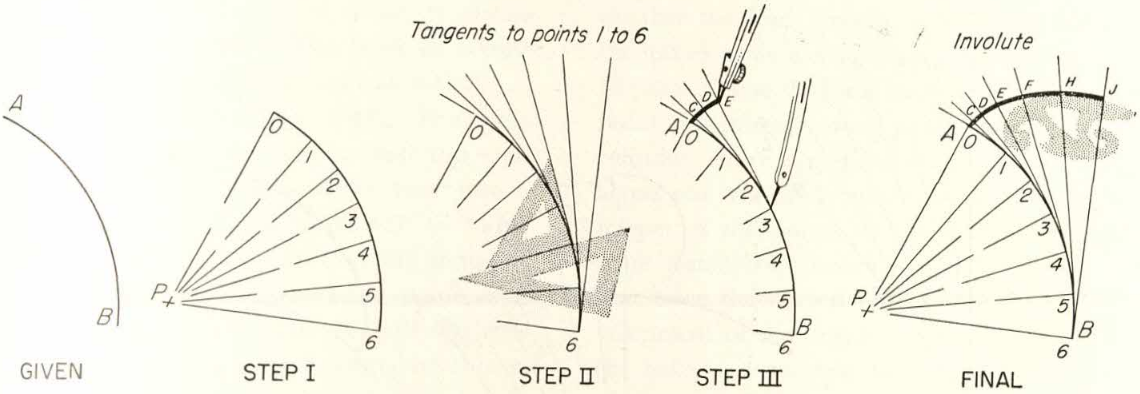


Fig. 5-42. To draw the involute of an arc.

From the points located on *CL* and with a radius equal to the radius of the circle, strike arcs intersecting the parallel lines at points P^1, P^2, P^3, P^4, and P^5, with point *B* locating the final position of the point *P* when it touches the line. When the center of the circle has reached point 1 on *CL*, point *P* has reached P^1 on the cycloid, etc. Draw a smooth curve through the points. To complete the cycloid, repeat the process for the portion on the left.

5-46. The construction of an epicycloid (Fig. 5-45). The curve generated by a point on the circumference of a circle as the circle rolls on a plane on the circumference of another circle is known as an epicycloid. The construction necessary is similar to that used for the cycloid. Line *AB*, a part of the circumference of a large circle, is equal in length to the circumference of the small circle. The small circle is divided into the same number of parts as *AB*, its path. The circular center line *CL* is drawn through *C*. Radial lines are drawn from *S*, the center of the large circle, through the points on *AB* to locate the points on *CL* that show the successive positions of the center of the small circle. With *S* as a center, swing circular arcs through the points 1, 2, 3, etc., on the small circle. With the points on *CL* as centers and radii equal to the radius of the small circle, strike arcs intersecting

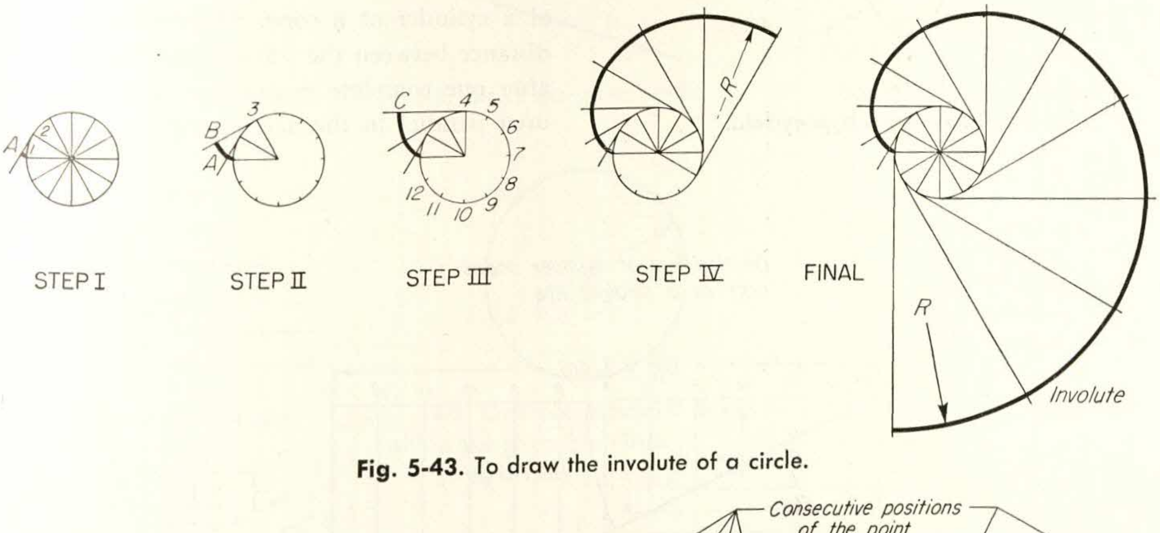


Fig. 5-43. To draw the involute of a circle.

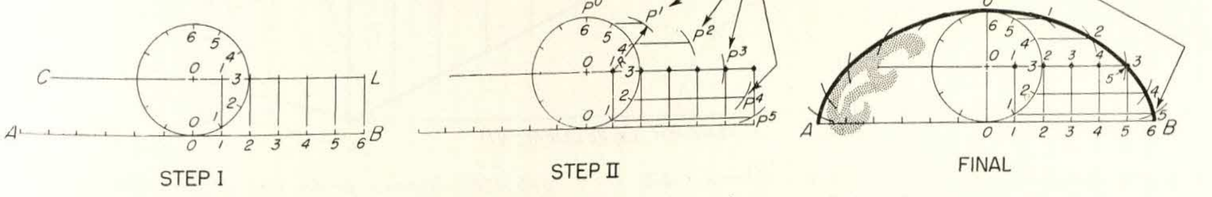


Fig. 5-44. To draw a cycloid.

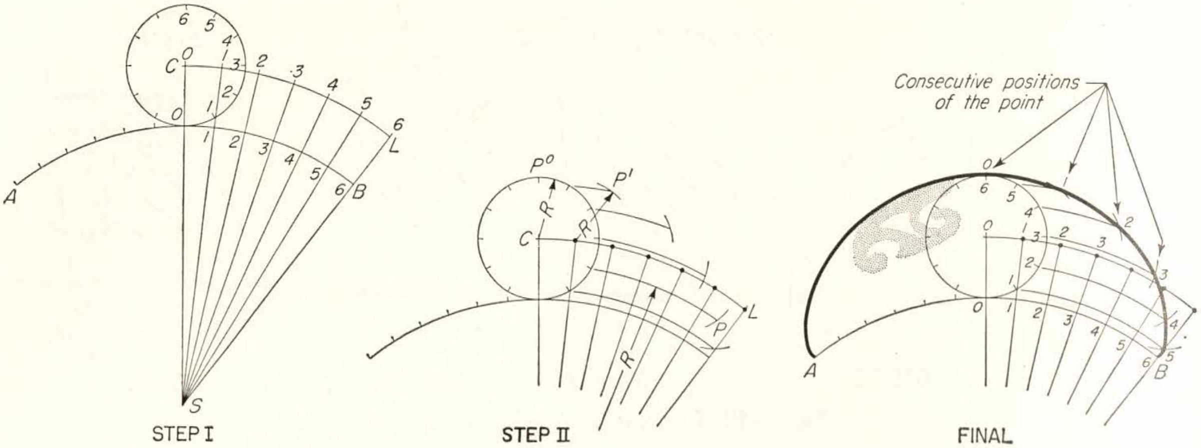


Fig. 5-45. To draw an epicycloid.

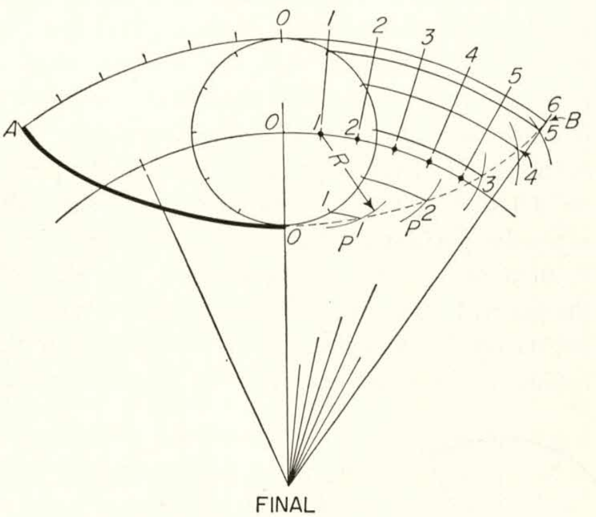


Fig. 5-46. To draw a hypocycloid.

those just previously drawn. The intersections of these arcs outline the form of the epicycloid.

5-47. The construction of a hypocycloid (Fig. 5-46). The curve generated by a point on the circumference of a circle as the circle rolls on a plane on the inside of another circle is called a hypocycloid. To draw the hypocycloid, follow the same general procedure used in the construction of the epicycloid.

5-48. The helix. The helix traces the curved path of a point as it revolves uniformly in both directions, around and up or down, on the surface of a cylinder or a cone. The *lead* is the vertical distance between the starting and finishing points after one complete revolution. It is always measured parallel to the axis of the cone or cylinder.

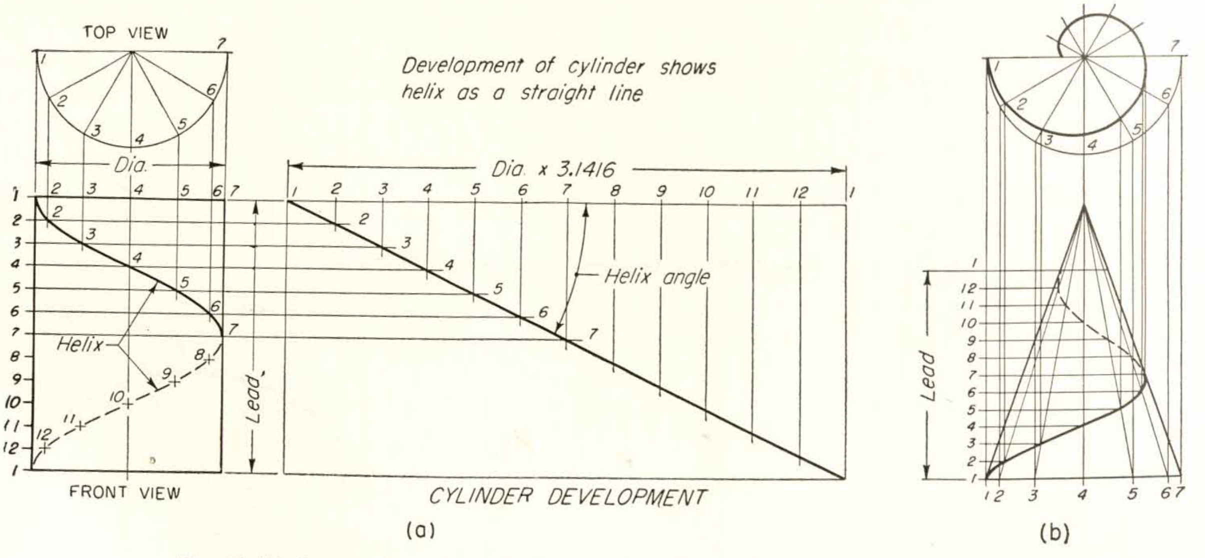


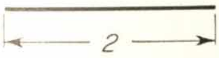
Fig. 5-47. (*a*) To draw the cylindrical helix. (*b*) To draw the conical helix.

When the word "helix" is used alone, it always refers to a cylindrical helix. The helix of a cone form is always referred to as a "conical helix."

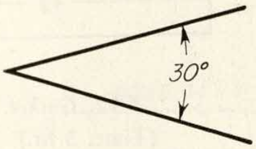
5-49. To draw a helix (Fig. 5-47). Draw the profile front view and the circular half top view of the cylinder. Divide the circular view into a convenient number of parts (say, 12) to locate the base points for the elements that will show the successive positions of the generating point as it moves around the cylinder. (In the half top view given in the illustration, only 7 points are shown, since the other five would project on points already indicated by numbers 2, 3, 4, 5, and 6.) Divide and number the lead (shown in the front view along the left extreme element) into the same number of 12 parts. These show the successive positions of the point as it moves upward parallel to the axis of the cylinder. Since the generating point will move across one unit as it moves upward one unit, projection of the points on the lead to intersect the same numbered elements will locate the points that trace the curved path of the helix. The development of the surface of the cylinder will show the helix as a straight line. Notice that the path of the conical helix (top view, Fig. 5-47*b*) resembles the spiral of Archimedes (Fig. 5-40).

PROBLEMS

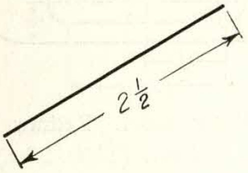
The following problems are intended to give the student practice in applying the geometrical constructions discussed in this chapter and to help him to become familiar with the use of the drawing instruments. All drawings should be executed with the utmost accuracy, and the line work must conform to the alphabet of lines as shown in Fig. 3-6. Problems 5-1 to 5-6 and 5-7 to 5-10 are located as shown on the standard 8½- by 11-in. sheet, and all dimensions are to be omitted. All other problems are also drawn on an 8½- by 11-in. sheet. Construction lines should be very lightly drawn. Points of tangency should be marked with a ⅛-in. line drawn across the points. Show all dimensions except those which serve to locate the views on the drawing sheet.



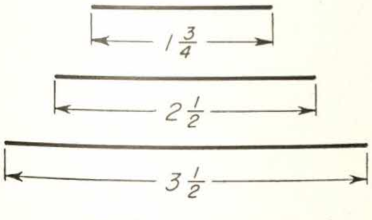
5-1. Bisect the given line.



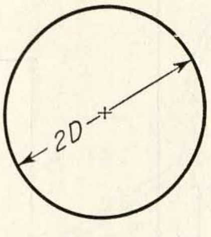
5-2. Bisect the given angle.



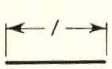
5-3. Divide the given line into five equal parts.



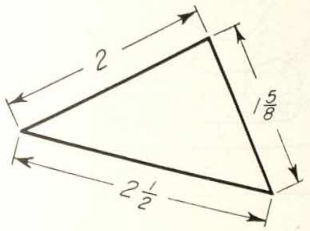
5-4. Construct a triangle of the three given lines.



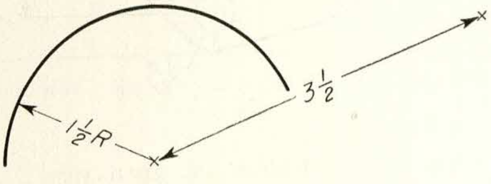
5-5. Construct a regular hexagon within the given 2-in circle.



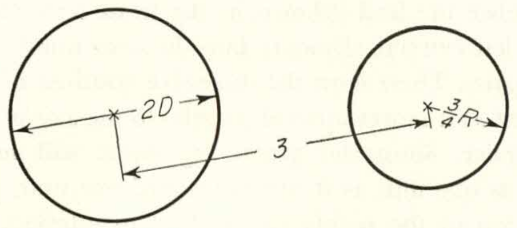
5-6. Construct a regular pentagon with the given 1-in. line as the length of one of its sides. (Total time for Probs. 5-1 to 5-6. 3 hr.)



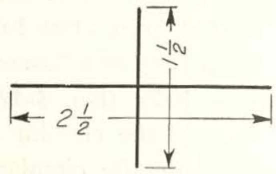
5-7. Divide the area of the given triangle into five equal parts.



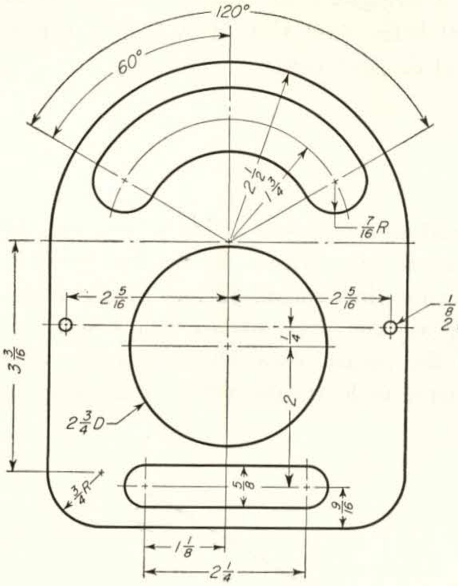
5-8. Construct a line tangent to the given arc from the given point *x*.



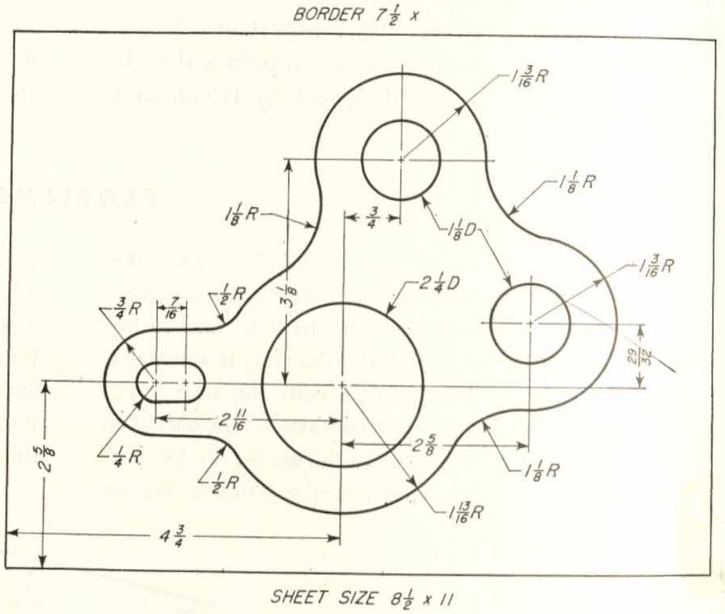
5-9. Construct a line tangent to the two given circles.



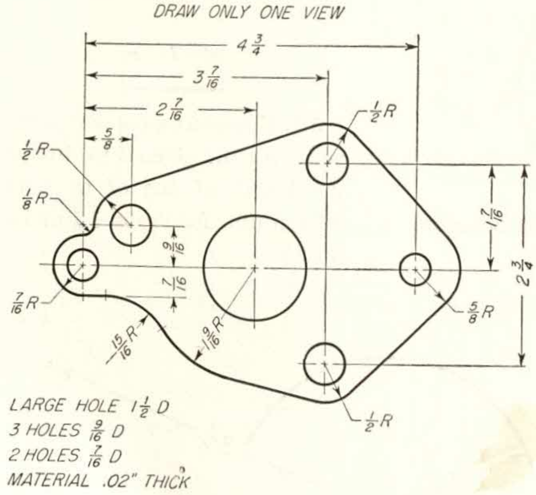
5-10. Construct an ellipse with the given long and short diameters. (Total time for Probs. 5-7 to 5-10. 2 hr.)



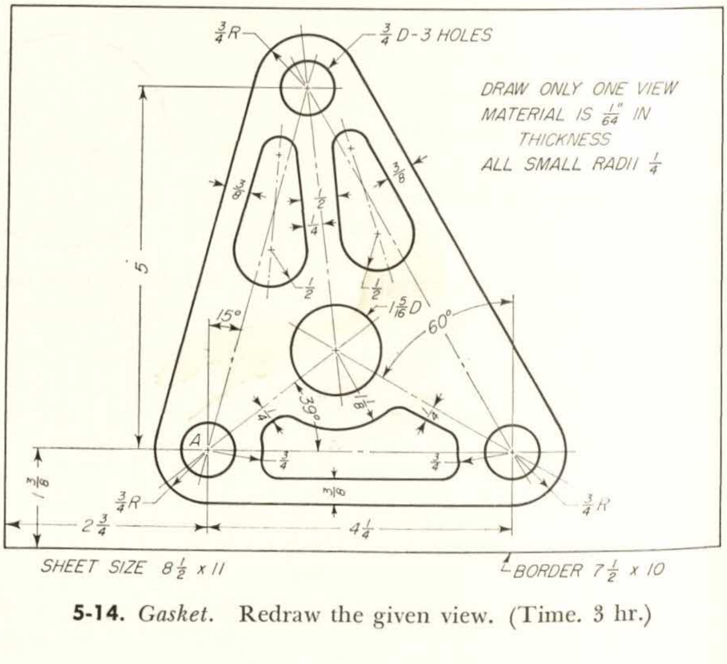
5-11. *Meter cover.* Redraw the given view in its entirety. (Time. 2 hr.)



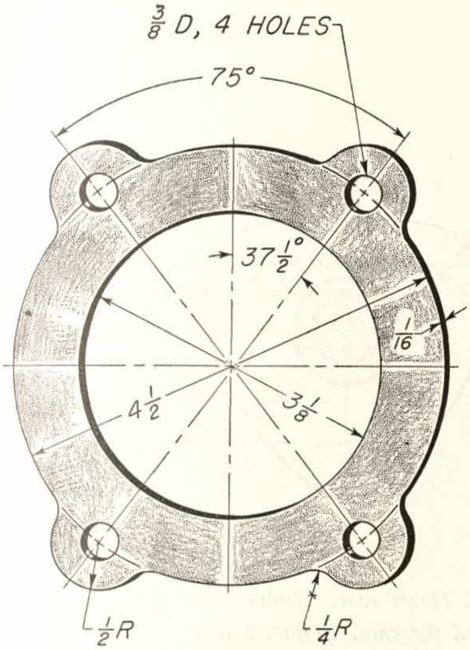
5-12. *Gasket.* Redraw the gasket shown in the figure. (Time. 3 hr.)



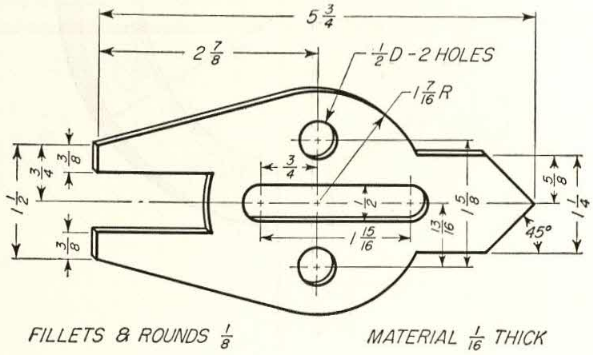
5-13. *Gasket.* Redraw the given view. (Time. 2½ hr.)



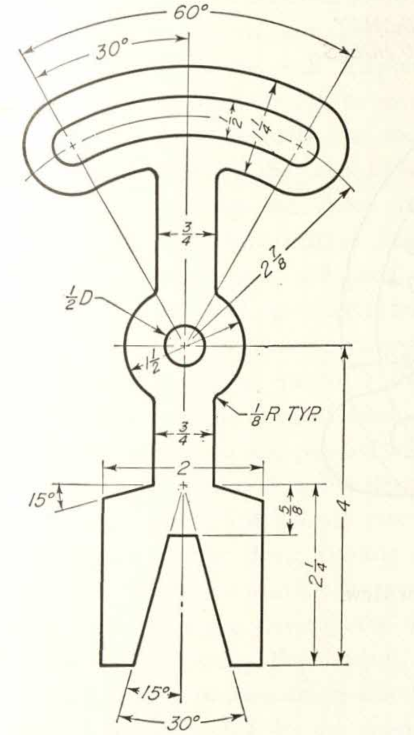
5-14. *Gasket.* Redraw the given view. (Time. 3 hr.)



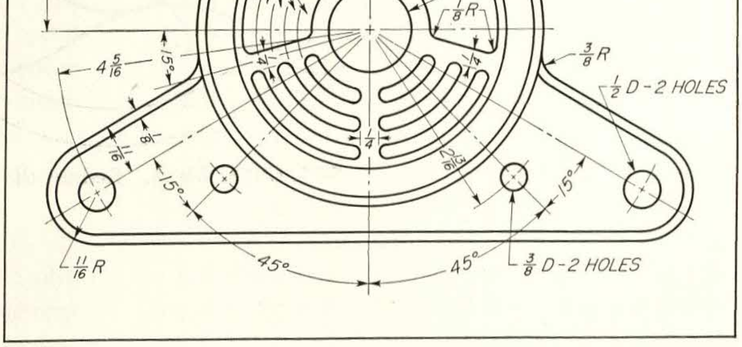
5-15. *Gasket.* Make a one-view drawing.



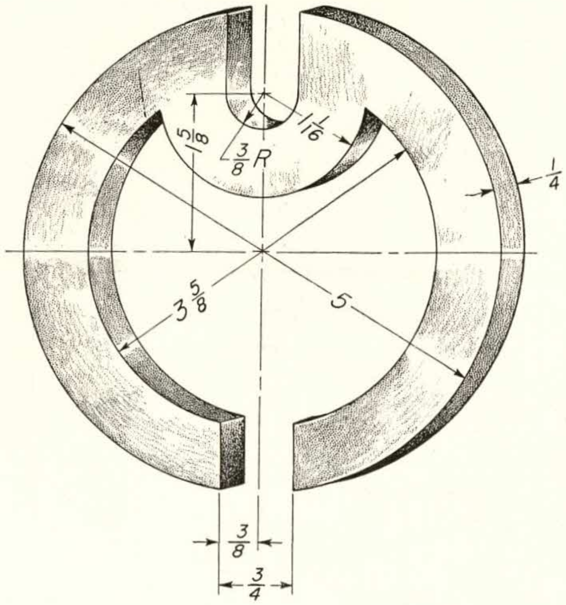
5-16. *Adjusting center device.* Make a one-view drawing. (Time. 3 hr.)



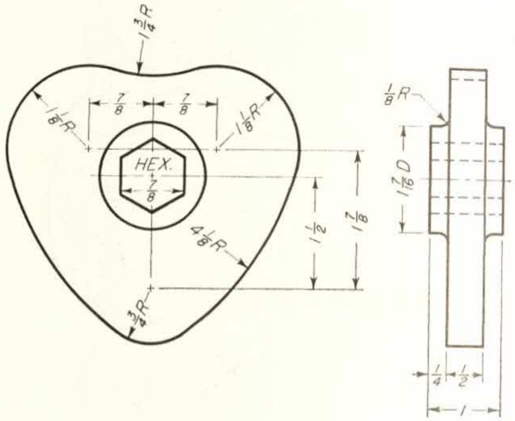
5-17. *Adjusting fork.* Redraw the given view. (Time. 2½ hr.)



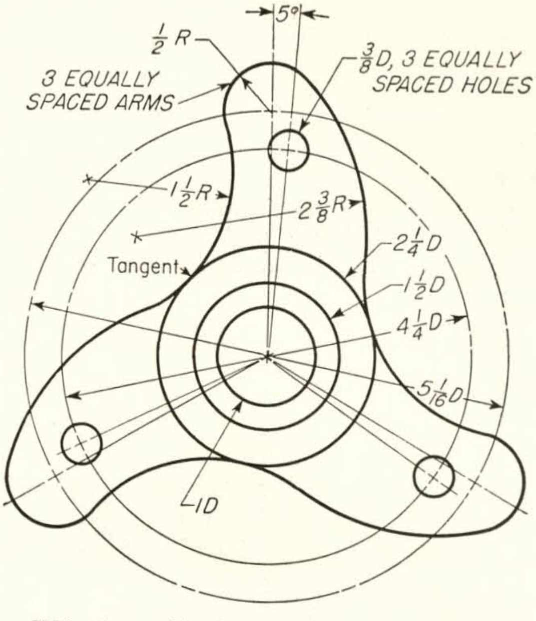
5-18. *Radio dial.* Redraw the view. (Time. 5 hr.)



5-19. *Guide.* Make a one-view drawing.



5-20. *Heart cam.* Redraw the given front and side views of the cam. (Time. 2 hr.)



5-21. *Cutter blank.* Redraw the given view.

Chapter 6

SHOP PROCESSES

In order to prepare working drawings that can be readily followed by the workmen in the shop, you should be familiar with the various shop processes and equipment. An accurate knowledge of the operations performed in the pattern, foundry, forge, and machine shops will frequently enable you to simplify the worker's job by means of helpful notes concerning the particular tools required and the manner in which they should be used. The most successful drawings are those in which the manufacturing requirements have been carefully analyzed, the proper and sufficient number of views have been selected, and well-chosen dimensions and explicit notes have been supplied so as to allow the shopmen to perform the necessary operations with a minimum of time, labor, and material. Whenever you are positive of the operation or procedure employed in the development or manufacture of a part, you should give such information as part of the dimensioning notes. You should always keep in mind the manufacturing processes required as you develop the notes.

Although a complete understanding of the various manufacturing procedures is obtainable only through actual experience in the shop, a description of the different processes will serve to familiarize you with the methods employed and allow you to prepare your drawings with an understanding of the basic principles involved in the manufacturing process.

Most manufactured objects and machine parts are produced by one of the following basic processes: casting, machining, forging, welding, and forming. Each process produces characteristic properties, and the manufacturing method selected is therefore directly related to the design of the part and the function it is to serve. Each of these manufacturing operations gives a distinctive appearance to a part, and these distinguishing features should be shown on the drawings you prepare. Sometimes these features are shown in the line work of the drawing, but more often they appear in the dimensioning and notes describing the part.

Although special drawings are sometimes prepared for the different procedures of planning, estimating, patternmaking, casting, welding, forging, machining, and assembling, a single general-purpose detail drawing in combination with an explicit assembly drawing can give all the necessary information for the performance of these tasks provided all the various operations and procedures in manufacture are specifically indicated as part of the dimensioning notes.

6-1. Castings. Castings are made by the cooling of molten metal in a specially constructed mold that has been made in the shape of the desired part. There are three basic casting processes: sand casting, permanent-mold casting, and die casting. Parts made of cast iron, steel, or alloys of the nonferrous metals are produced by sand casting, while

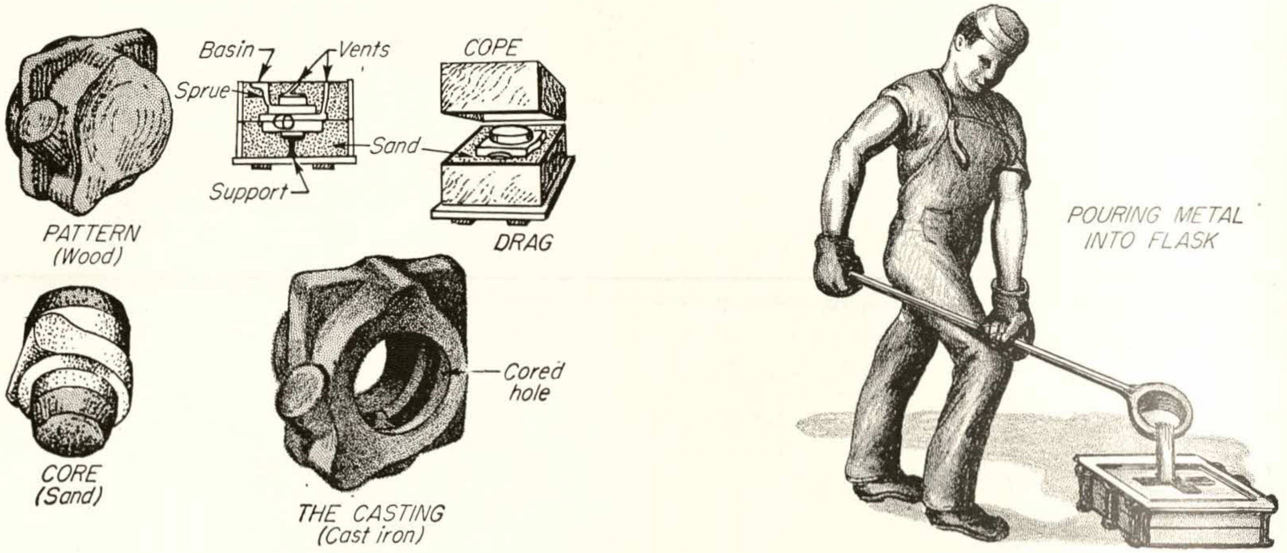


Fig. 6-1. Sand casting: the pattern, mold, core, and casting.

the white metals (aluminum, zinc, etc.) and copper alloys are generally produced by permanent-mold casting or by die casting. In sand and permanent-mold casting, the molten material is poured freely into the forming mold; in die casting, the molten metal is forced into a mold, or "die," under great pressure, which is maintained until the material has cooled and hardened.

6-2. Patterns and the pattern shop. Before a mold can be constructed, a pattern (which is really a model of the object) must be made in the pattern shop (see Fig. 6-1). Patterns are generally made from the softwoods. If they are to be used repeatedly (as in permanent-mold casting), they are made of zinc, aluminum, or plastic. In the preparation of the pattern, a slight taper known as "draft" is given to all surfaces to permit its easy removal from the mold. The pattern is also made slightly larger than the final desired size of the casting in order to allow for shrinkage of the cooling metal and for the machining of surfaces. Cast iron may shrink as much as $\frac{1}{8}$ in. per ft although $\frac{1}{16}$-in. allowance is usually sufficient for small pieces. Shrinkage in white metals varies but is less than that of the ferrous metals. Allowance for shrinkage is taken care of by the patternmaker and is not the concern of the draftsman. Occasionally the draftsman may prepare a drawing especially for the patternmaker's use, although in most instances the standard detail drawing will suffice. The material of which a casting is to be made and the number of castings required generally govern the type of pattern that should be constructed.

6-3. Molding. Molding is usually done in a sand base, although plaster, steel, wood, and paper may also be used. Where great accuracy is desired, either permanent-mold casting or die casting is employed. These processes produce castings with smoother surfaces and more accurate dimensions, and thus fewer machining operations are required to finish the product (Fig. 6-2). Permanent molds and dies are most often made of metal. They are used many times over and are expensive to produce. Sand casting is better adapted to a great many objects and is particularly suitable when the object to be cast contains many holes and other voids that require coring. Most products that can be cast can also be produced by forging.

Green sand (or *damp*) *molds* are used for cast iron. These are made of a mixture containing 8 per cent silica, 15 per cent bonding clay, a minimum of other necessary ingredients, and a small amount of water. *Dry sand molds,* containing a coarser-grained sand and, instead of water, usually mixed with linseed oil, molasses water, or other suitable bonding substances, are recommended for steel castings. These are dried in air, by torch, or in heated ovens. In making the mold, the pattern is placed on a *molding board* which fits the lower half of the *flask.* The flask consists of an upper part, the *cope,* and a lower part, the *drag.* Additional parts called *cheeks* may be placed between the cope and the drag for more complicated work. The molding sand is packed tightly around the pattern and inside the flask. After this has been done, a *bottom board* is placed over the top of the completed lower drag half and the assembly is turned over. The molding board is now removed, and a fine coating of dry parting sand is spread over the surface of the lower mold to prevent adherence when the mold halves are separated to permit removal of the pattern. The cope half is now placed over the drag half. A *gate sprue pin,* the opening through which the metal is poured, is placed on a side of the mold, opposite which another sprue pin known as a *riser* is located. The riser holds the molten metal that will feed to the casting as shrinking occurs. Sand is again packed tightly around the pattern and sprue in the cope half of the flask. When the mold is completed, the sprue pins are removed and a funnel-shaped opening is fashioned at the top of the gate-sprue-pin hole. The cope is then lifted from the drag and the pattern carefully removed. Vents for the escape of air, gas, or steam are provided. If the casting is to contain holes or other voids, *cores* made of dry sand and in the proper shape are set in position. The flask is then closed, both halves being held together by pins or other locking devices, and is readied for the pouring of the molten metal.

When the metal has hardened completely, the flask is opened to reveal the sand-encased casting. Unless other castings are required, the sand is broken, air-blasted, and washed from the surfaces of the casting. Upon inspection, a casting will always reveal various surface imperfections occurring at seams, at points where the metal has been poured (gates), at air and gas escape vents (risers), at air pockets, etc. The larger excess metal formations may be removed on a band saw or with the chisel of a pneumatic chipping hammer (Fig. 6-3). Smaller surface imperfections may be smoothed down with portable abrasive wheels.

6-4. Fillets and rounds. The rounded intersection of surfaces at an inside corner of a casting is called a *fillet;* the rounded intersection of surfaces at an outside corner is known as a *round.* Properly selected fillets are desirable features in a casting since they provide the required strength in those areas. Rounds improve the appearance and permit safe and easy handling of the piece (see discussion appearing in Secs. 3-14, 3-15, and 8-28).

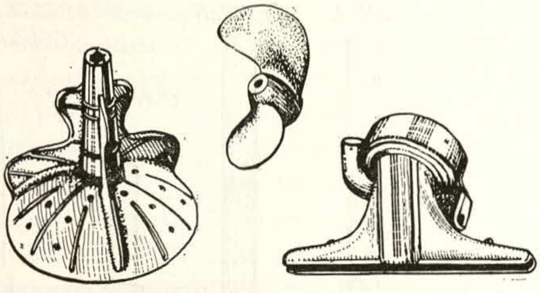


Fig. 6-2. Permanent mold and die castings.

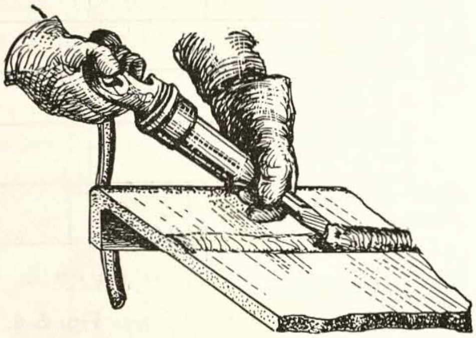


Fig. 6-3. The pneumatic chipping hammer.

6-5. Machine-shop processes. The draftsman should become thoroughly familiar with the various machine-shop operations and the machines on which they are performed, because in dimensioning a part the draftsman frequently must specify the exact operation required. Although there are a great many different operations employed in the machine shop, machining processes may in general be classified as those which (1) make holes, (2) remove metal, (3) shape to close accuracy, or (4) further refine surfaces by the use of manual or power-driven tools.

A few common machining operations and the tools that perform them are shown in Fig. 6-4. In the sections that follow, the important machine-shop processes are discussed in detail.

6-6. Facing and turning. Facing and turning are operations that are performed on the lathe. Usually, in the operation of a lathe, the piece to be worked is held and turned by a rotating vise called a "chuck," and the metal is removed by a nonrotating cutter. When the cutter moves perpendicular to the axis of the workpiece, the operation is known as *facing;* when it moves parallel to the

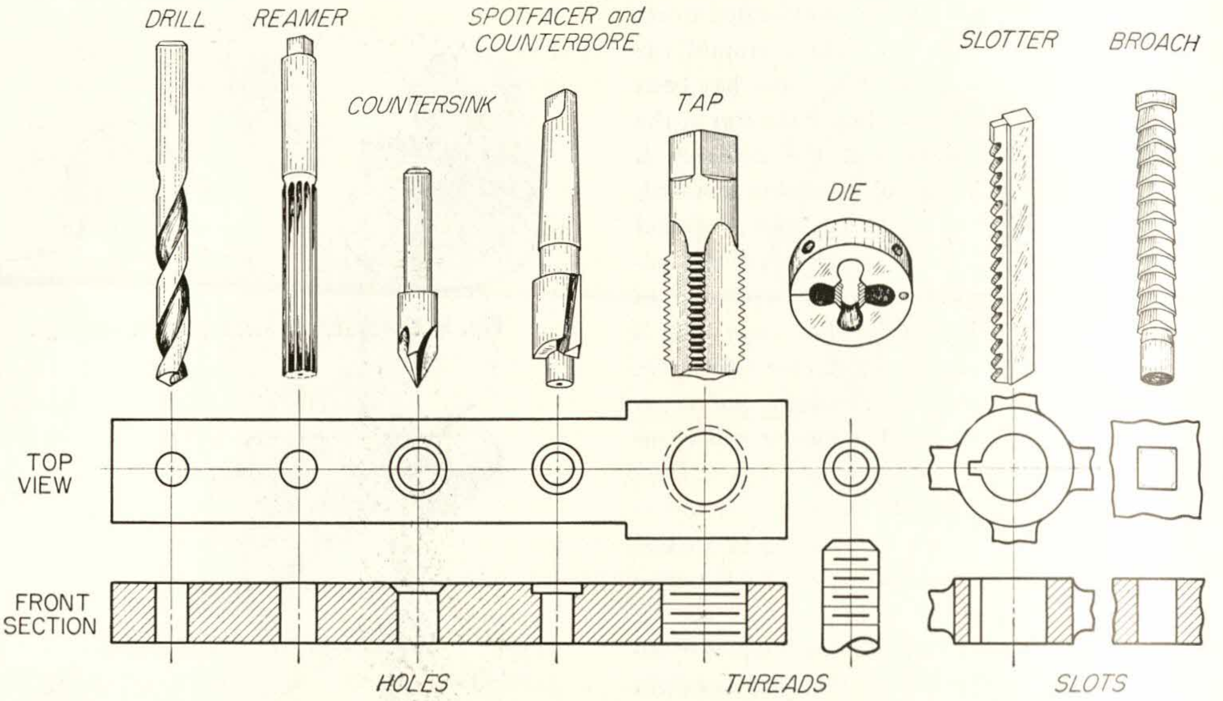


Fig. 6-4. Machine-shop operations.

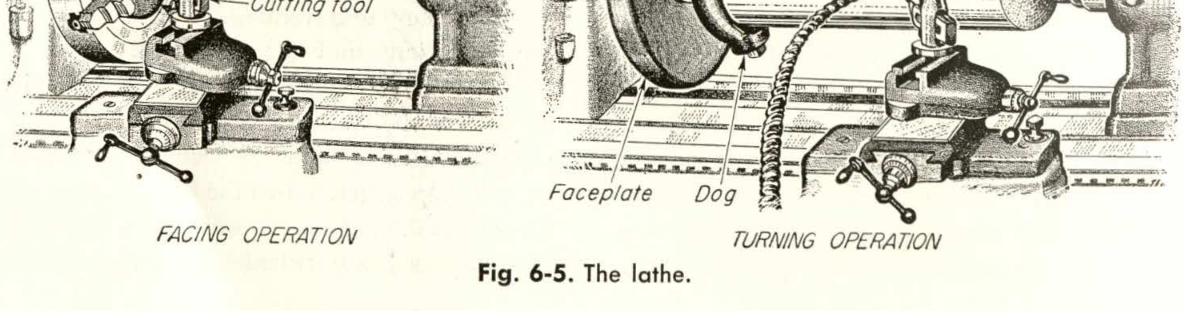
workpiece axis, the operation is called *turning* (see Fig. 6-5).

6-7. Drilling. Drilling may be accomplished on a lathe or a milling machine, but the drill press is the machine designed for this operation. In this machine, the tool turns and can be raised and lowered while the work is held in a fixed position (see Figs. 6-4 and 6-6).

6-8. Reaming. Drilled holes are rarely absolutely straight, cylindrical, or accurate in size. To "true" them, they are reamed out by a tool that removes the riflings left by the drill. This operation can be performed on any machine that can be used for drilling (see Fig. 6-4).

6-9. Boring. Because reaming does not always "true" the straightness or roundness of a drilled hole, boring should be indicated when great accuracy is required. The boring of small holes can be accomplished on a lathe (Fig. 6-7). A boring mill is used for the larger tasks.

6-10. Milling. Milling-machine operations are among the most comprehensive accomplished in a



FACING OPERATION

TURNING OPERATION

Fig. 6-5. The lathe.

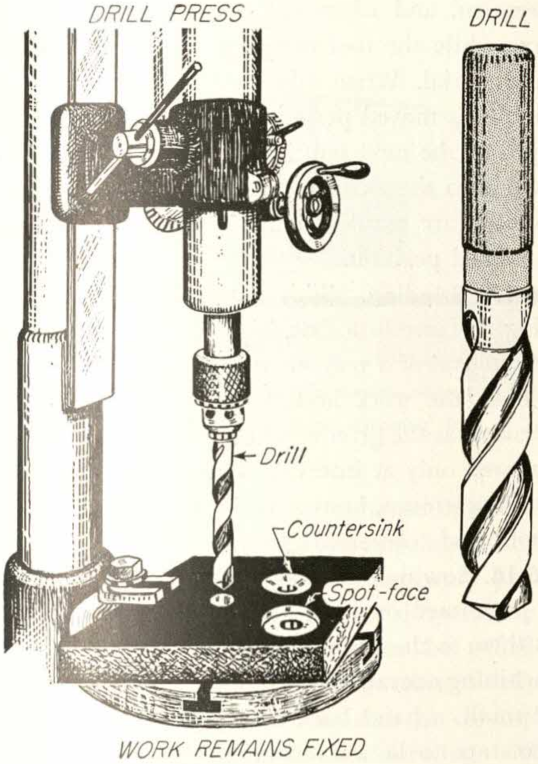


Fig. 6-6. The drill press.

machine shop. Gear cutting and shaping are perhaps the most common jobs done on a milling machine. The milling-machine cutter is usually shaped to the desired appearance of the cut required, and it turns until the cut is completed. The work is then moved to the next position for the succeeding cutting operation (see Fig. 6-8).

6-11. Shaping. This operation is performed on a machine called a *shaper*. The work is surfaced by a reciprocating cutting tool that moves at regular intervals across the face of the material that is being shaped. The work remains stationary while the cutting tool is engaged, but it can be raised toward the tool if a second or third operation is required (see Fig. 6-9).

6-12. Planing. Large or heavy surfacing operations are accomplished on a planer (Fig. 6-10). The work is fastened to a reciprocating table that passes beneath a cutting tool that is fed into the material as the operation progresses. Some planers have cutting tools mounted at various positions on their large frames that can perform other machining operations. The planer and the shaper are designed primarily for cutting plane surfaces, however.

6-13. Broaching. Broaching is a single-stroke operation used to cut keyways and square and hexagonal holes and those of other shapes (see Fig. 6-4). The cutting tool, called a "broach," is either pushed or pulled through the workpiece, and it bites deeper into the metal with each succeeding tooth. A previously drilled or cored hole must be prepared, and a special machine that produces precision results is needed for this rapid operation.

6-14. Threading. Threads are cut on a milling machine or a lathe, or by the use of collapsible or fixed taps and dies (see Fig. 6-4). Expediency and sometimes the material to be worked suggest the best method. The screw thread is one of the important fastener devices. It is made by a turning

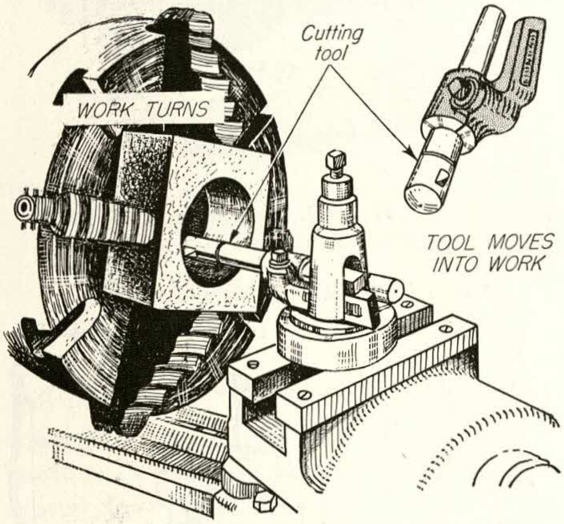


Fig. 6-7. Boring on a lathe.

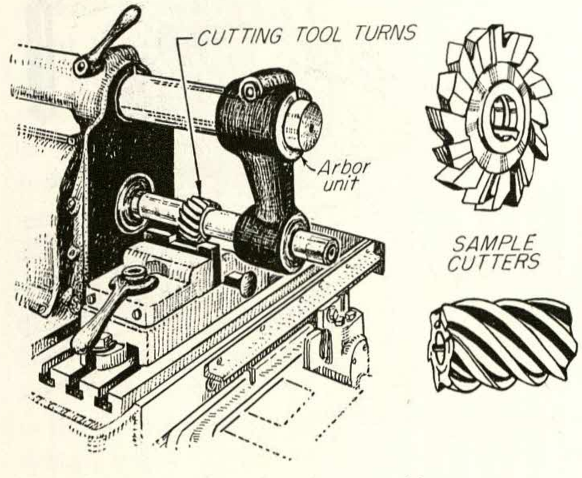


Fig. 6-8. The milling machine.

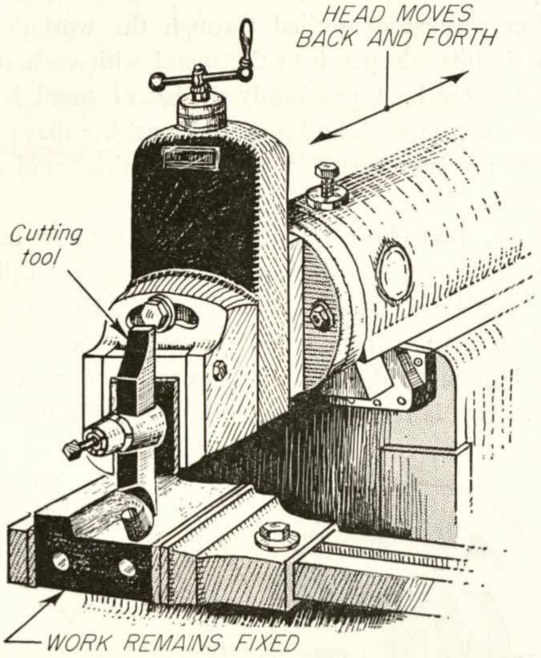


Fig. 6-9. The shaper.

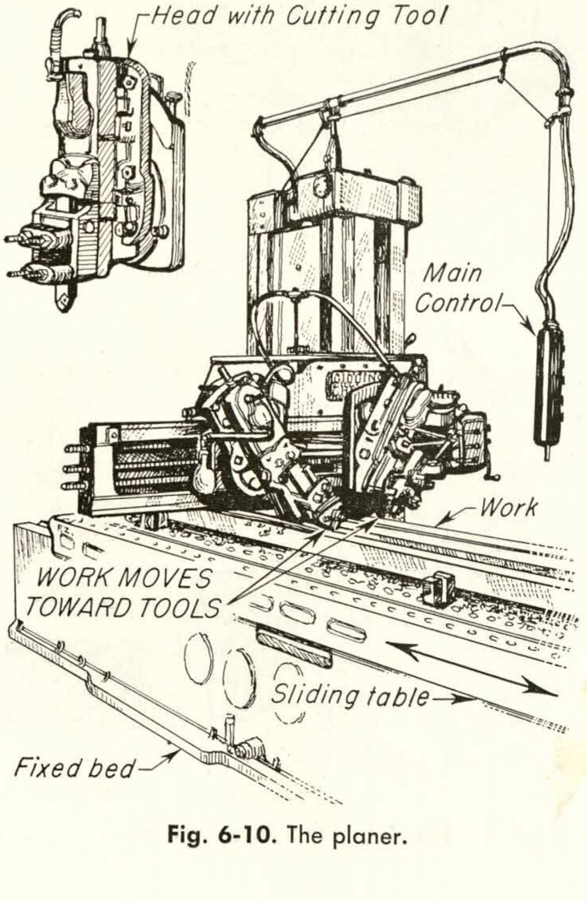


Fig. 6-10. The planer.

operation, and when cut on the lathe, the work turns while the tool moves parallel to the axis of the material. When additional cuts are required, the tool is moved perpendicular to this axis to the depth of the next required cut, and then it moves parallel to the axis to finish the operation. If taps and dies are employed, the work usually remains in a fixed position.

6-15. Grinding. This operation, intended to bring surfaces to a fine finish, is accomplished by the removal of a very small amount of the material as both the work and the grinder turn at high speeds or as the grinder wheel turns while the work is moved only at intervals. Grinding machines fall into four groups, known as "surface," "cylindrical," "tool," and "centerless grinders" (see Fig. 6-11).

6-16. Sawing. Sawing operations must often be performed on rods, bars, or thick flat pieces to cut them to the desired size as preparation for later machining operations with other tools. If the pieces are small, a hand hack saw may be used. If many pieces are to be cut, hand sawing can be a time-consuming and expensive operation. Therefore, large or numerous pieces are more economically handled by using a power-driven metal-sawing machine of the circular, reciprocating, or band types. Figure 6-12 shows a power-driven circular saw in which the work is clamped between the viselike jaws on the bed and is fed into a toothed disk which revolves at a speed selected for the material being worked.

6-17. Shearing. The simple trimming, slitting, and parting operations may be performed with a tinner's shears or a power-driven machine having cutting features similar to the one shown in Fig. 6-13. Certain operations, where use is made of ma-

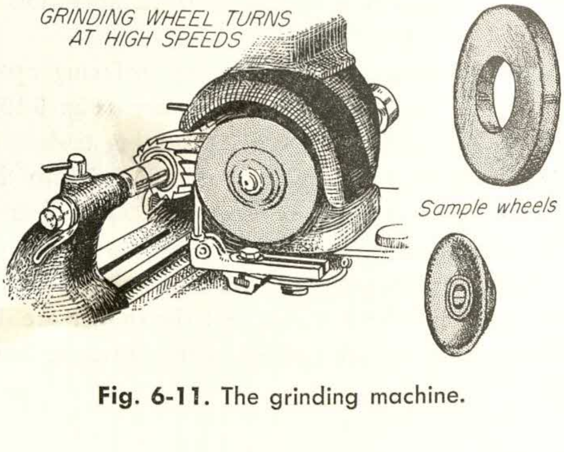


Fig. 6-11. The grinding machine.

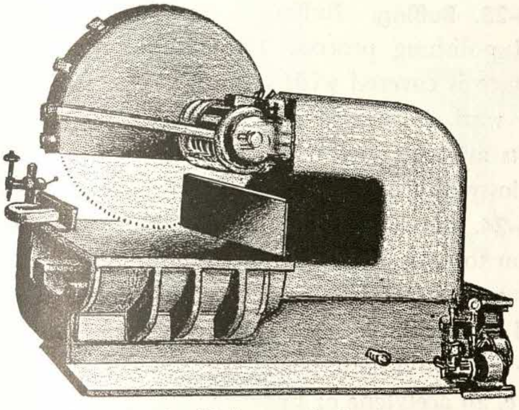


Fig. 6-12. High-speed circular saw.

chines equipped with specially shaped dies that are forced through thin material to stamp out, or "shear," required designs, may be included, in a broader sense, under the heading of shearing operations.

6-18. Rolling. Sheet metal may be rolled on hand-operated or power-driven machines designed to produce cylindrical forms such as cans, pails, drums, corrugations, etc. The roll forming machine in Fig. 6-14 is manipulated by hand. Its forming mechanism consists of three rollers, two of which lie in a horizontal and parallel position, while the third rests above the lower two. The sheet metal is fed between the upper and one of the lower rollers, and as the metal moves through the machine, it is shaped by the action and pressure of the other lower roller. A complete cylindrical form will encircle the upper roller. It is removed from the machine by removing both the roller and the formed metal.

6-19. Folding and bending. Sheet metal is folded or bent in a simply constructed machine called a "brake" consisting of two flat metal straightedges placed one above the other (see Fig. 6-15). The upper straightedge blade remains fixed, while the lower one, the jaw, bends or folds the material over the blade edge when force is applied by means of a geared hand-manipulated transmission. Flanging, seaming, and crimping are performed on special hand-manipulated or power-driven tools but may be classified as rolling, folding, and bending operations.

6-20. Punching. Many of the large tools found in a quantity-production machine shop can be adapted to a number of different operations. The punch press, for example, is a machine that may be used for bending, folding, seaming, cupping, embossing, flattening, riveting, shearing, notching, punching, stamping, and many other tasks which depend upon the selection of a suitable combination of punches and dies. In the operation of the punch press, the die rests on the press bed, and the material is placed on it. The punch, which is fastened to the head, is lowered and forced against (or through) the material while the die cavity transmits its shape to the work. To ensure successful operation, the tool and die must be firmly attached to the machine frame and in perfect alignment with each other. Figure 6-16 shows a heavy-duty punch press.

6-21. Lapping. If very accurate fits are required, lapping will serve to bring the mating surfaces to a true finish. In this process, a very fine abrasive is mixed with oil or kerosene and applied to the mating surfaces. The adjacent parts are then rubbed together until the desired smoothness and fit are obtained.

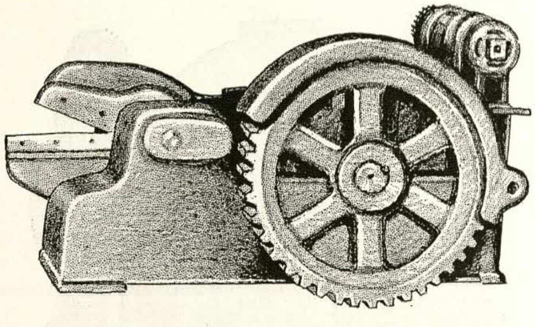


Fig. 6-13. Heavy-duty shears.

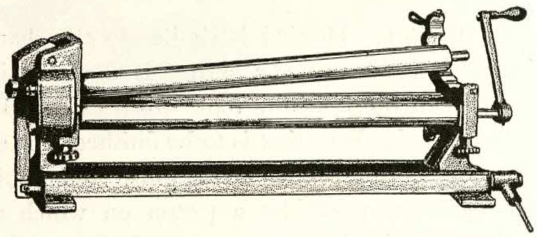


Fig. 6-14. Roll forming machine.

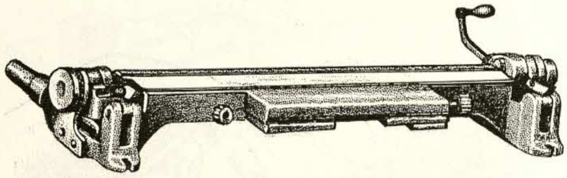


Fig. 6-15. Folding and bending machine.

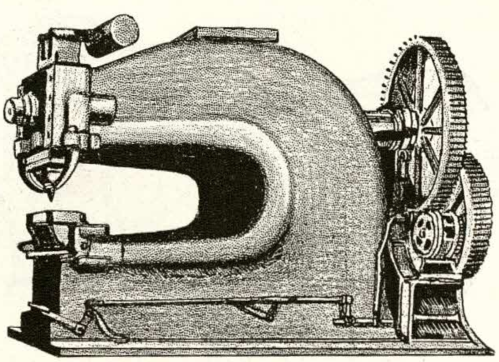


Fig. 6-16. Geared punch press.

6-22. Honing. Honing is similar to the sharpening done to a razor. An extremely fine abrasive is applied to the finishing tool, which often takes the shape of the form that is to be finished. For example, the honing tool used to finish automobile block cylinders resembles a piston on which an abrasive material has been mounted. A very fine, smooth finish is the result of a honing operation.

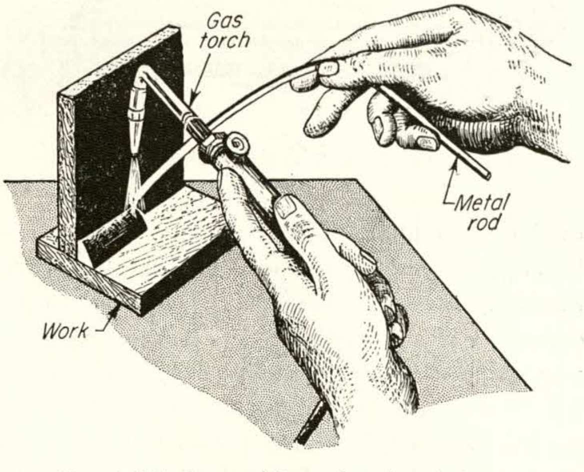


Fig. 6-17. Gas welding—hand technique.

Fig. 6-18. Hand torch welding.

6-23. Buffing. Buffing is primarily a cleaning and polishing process. The pliable buffing-wheel surface is covered with wax and soft abrasives. As the work is pressed against the wheel, the high spots are smoothed down and the surface is given a glossy finish.

6-24. Welding. The draftsman may be called upon to show welded forms. Welding brings about the permanent joining of several pieces of metal and is one of the most effective ways of obtaining gas- or liquid-tight seams. In the simplest procedure, an acetylene or hydrogen flame is used as the heating agent, and a suitable filler material is required. No pressure is needed to bring the forms together (see Figs. 6-17 and 6-18).

Seam and spot welding are examples of electric resistance welding (see Fig. 6-19). These methods are ideally suited to the fabrication of small subassemblies that can be handled by one or two operators. The electric current passing through the welding electrodes brings the material to the fusion point. Pressure is then applied, and the parts are permanently joined. Electric welding results in smoother finishes than those obtained by gas welding or riveting and in many cases proves more economical.

See Secs. 12-32 to 12-35 for a more detailed discussion of welding, types of welding, and welding symbols.

6-25. Forging. The aforementioned operations, with the exception of welding, are classified

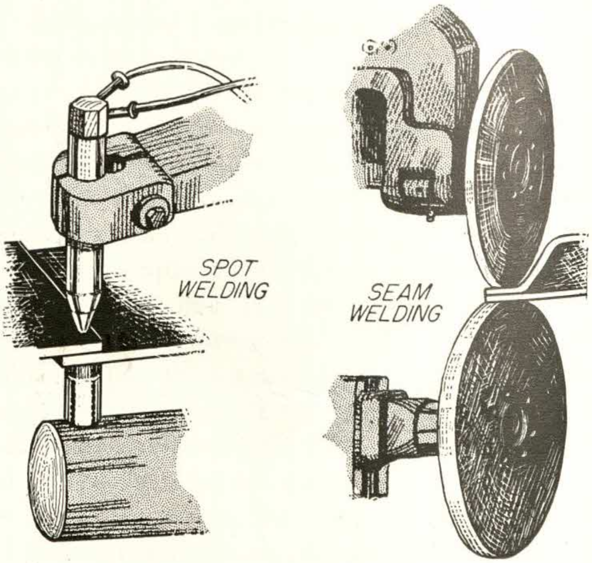


Fig. 6-19. Electric resistance welding.

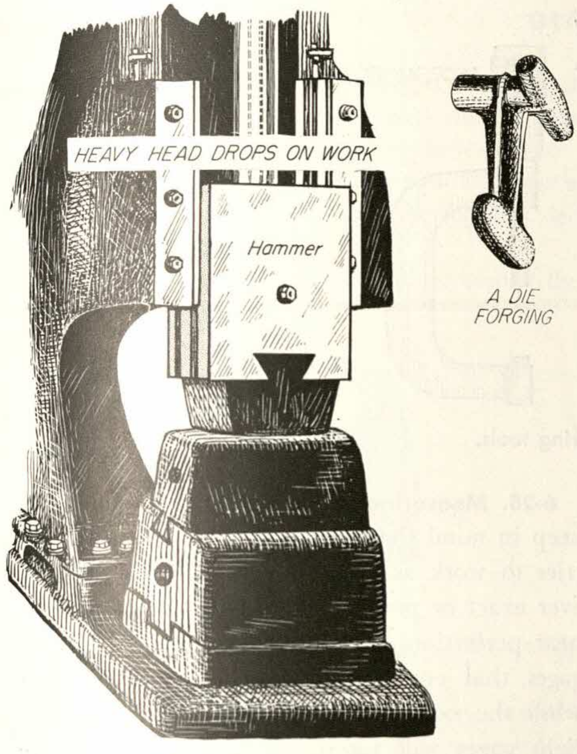

HEAVY HEAD DROPS ON WORK
Hammer
A DIE FORGING

Fig. 6-20. Forging press.

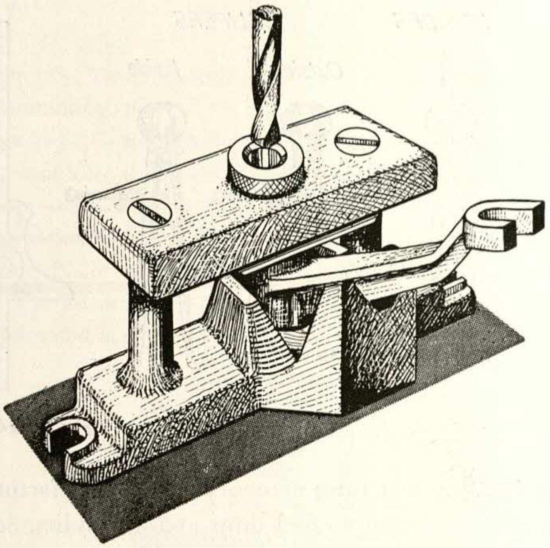


Fig. 6-21. A drill jig.

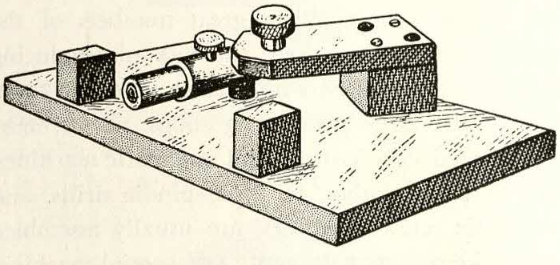


Fig. 6-22. Jig used on an automatic machine.

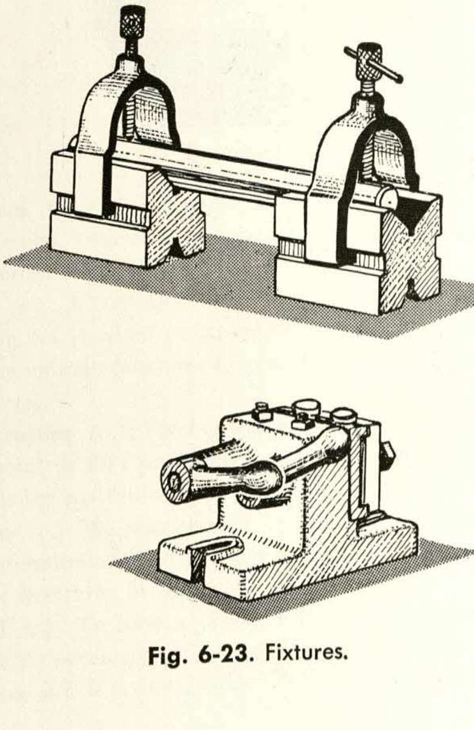


Fig. 6-23. Fixtures.

as cold-working processes. Forging, however, may be accomplished by either cold- or hot-working the material. A press or heavy hammer (Fig. 6-20) is used to exert great pressure and to force the metal to "flow" into the desired shape. The use of dies depends on the type of forming desired. Few metals lend themselves to cold forming because of the breakdown of the basic structure of the component elements while being forced into shape; consequently, most forging is done with hot or molten metal. Forgings are classified as drop, press, extrusion, smith, and machine forgings, according to the type of forging press used.

6-26. Jigs and fixtures. These special tools are useful in operations of many kinds, especially in the manufacture of duplicate or interchangeable parts. They facilitate production and lead to economical use of time and manpower. A jig is a device that both holds the work and guides the tool (see Figs. 6-21 and 6-22). A fixture (Fig. 6-23) simply holds the part as it is being worked. Most jigs and fixtures found in small shops are of the type shown in Figs. 6-21 and 6-23 and are usually employed in the cutting operations such as drilling and reaming. In the very large manufacturing plants, the terms jigs and fixtures would also refer to the huge tooling docks and other directing and

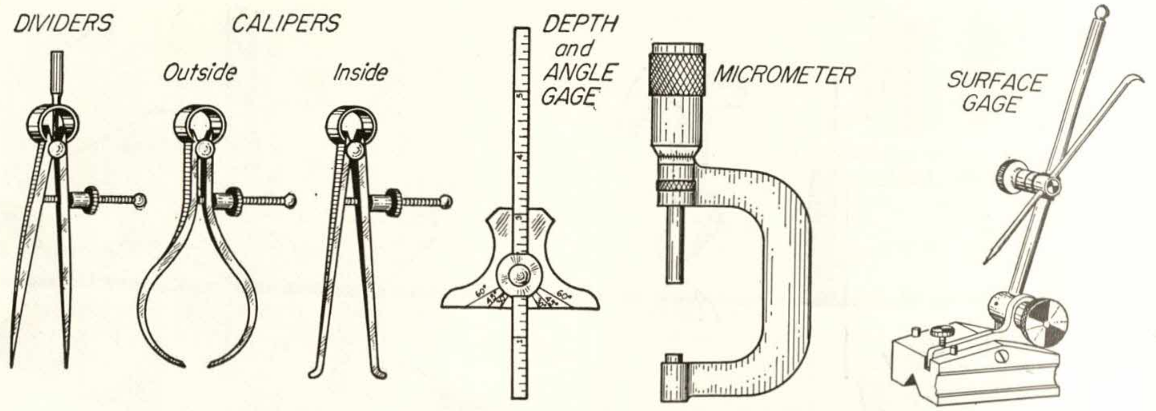


Fig. 6-24. Measuring tools.

positioning structures necessary to the manufacture of large and complicated units and assemblies. See Secs. 17-19 to 17-31 also.

6-27. Automatic machines. Practically all the operations mentioned in the preceding sections in this chapter can be performed in any well-organized jobbing shop. When great numbers of the same pieces are required, the task of producing them is accomplished with greater all-round economy in the large production shops, where many complicated jigs, fixtures, and automatic machines, such as turret lathes, multiple-spindle drills, and automatic screw machines, are usually assembled under the one management. The special machines perform certain particular operations without the necessity of being under constant surveillance or requiring continuous manipulation by the worker.

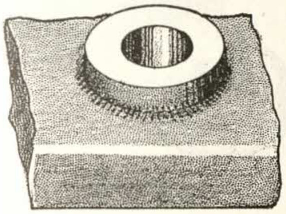
6-28. Measuring tools. The draftsman must keep in mind that, although the man in the shop tries to work as accurately as possible, no job is ever exact or perfect. To aid the worker to reach near perfection, he has available various types of gages that enable him to check his dimensions while the work is in progress. If required, air and light gages will point out errors of a hundred-thousandth or even a millionth of an inch. For ordinary precision work, however, it is permissible to maintain tolerances to thousandths or ten-thousandths of an inch. Some of the simpler measuring devices are shown in Fig. 6-24. Most measuring tools have a scale by means of which the dimensions can be read directly; when this is not the case, the settings can be referred to a separate scale for the readings.

GLOSSARY

Anneal (*v.*). To soften metal by heating it to its critical temperature and allowing it to cool slowly. This operation removes internal stresses in the material.

Bore (*v.*). To enlarge or "true" a hole with the use of a boring bar mounted on a lathe or boring mill. See Fig. 6-7.

Boss (*n.*). A circular projection extending beyond the surface of a casting or forging.



Boss

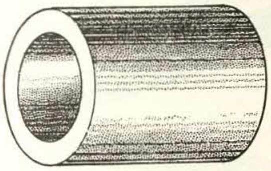
Braze (*v.*). To join together by a hard solder usually consisting of a copper and zinc alloy.

Broach (*n.*). A cutting tool with transverse serrated edges that is pushed or pulled in a hole to cut it to a desired shape. See Fig. 6-4.

(*v.*). Machining or enlarging a hole to a desired shape, usually other than round.

Buff (*v.*). To smooth and polish with a soft wheel carrying an abrasive.

Burnish (*v.*). To smooth to a brilliant finish with a tool applied with great pressure.



Bushing

Bushing (*n.*). A cylindrical sleeve that serves as a bearing surface or as a guide for a tool (in a jig or fixture). See also Fig. 17-18.

Carburize (*v.*). To harden the surface of a soft steel by heating in carbonizing material and permitting to cool slowly.

Caseharden (*v.*). To harden a carburized steel by heating and quenching in oil or lead.

Chamfer (*v.*). To bevel an external edge.

(*n.*). A beveled edge or corner. See Fig. 7-29*A*.

Chase (*v.*). To cut threads on a lathe with a tool shaped to form the desired thread.

Chill (*v.*). To produce a harder portion in a casting through rapid cooling by placing it in contact with cold metal plates in the wall of the mold.

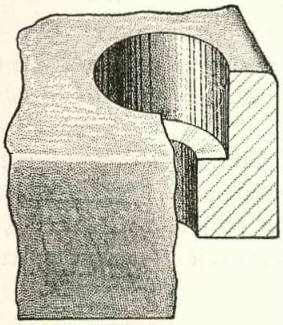
Chip (*v.*). To cut, trim, or clean with a chisel. See Fig. 6-3.

Coin (*v.*). To stamp into shape with the use of a design-containing die.

Core (*v.*). To form the hollow parts of a casting by using a sand core that is easily broken away after the casting has cooled. See Fig. 6-1.

Counterbore (*v.*). To enlarge the end of a drilled or bored hole to a certain depth. See also Fig. 6-4.

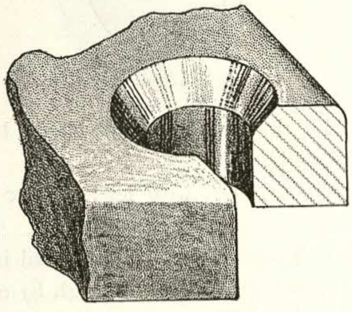
(*n.*). The tool used for a counterboring operation. The pilot end is equal to the size of the hole to be enlarged.



Counterbore

Countersink (*v.*). To form a conical depression in a hole, usually to accommodate the head of a screw. See also Fig. 6-4.

(*n.*). The conical tool used for this operation.



Countersink

Crown (*n.*). The angular or rounded contour of a circular form such as may be seen on the face of a pulley. See Fig. 7-32.

Die (*n.*). A tool used for cutting external threads. See Fig. 6-4. A metal block used in forging, stamping, and die-casting operations to give the desired shape to the metal.

Die casting (*v.*). Forcing molten metal into permanent molds or dies producing parts requiring little or no further machining. See Fig. 6-2.

Draw (*v.*). To temper steel by quenching gradually or intermittently. To produce a desired shape in metal by stretching or distorting it.

Drill (*v.*). To form a cylindrical hole in a part.

(*n.*). A pointed cutting tool that produces a cylindrical hole as it is revolved under pressure. See Fig. 6-6.

Drop forging (*n.*). A piece that has been shaped while hot between dies acted upon by a heavy hammer. See Fig. 6-20.

Face (*v.*). To machine a flat surface on a piece as it turns in the headstock of a lathe or rests on the bed of a shaper. See Figs. 6-5 and 6-9.

Feather (*n.*). A rectangular key which permits the hub to slide parallel to the axis of the shaft. See Fig. 12-33.

File (*v.*). To cut, trim, shape, or finish by hand and file.

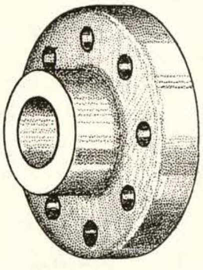
Fillet (*n.*). A rounded inside corner of a part, tending to give added strength to the angle formed by the sides. See Fig. 3-14.

Fin (*n.*). A thin projecting rib.

Finish (*v*). To machine a (comparatively rough) surface to a closer dimensional accuracy or to the surface required.

Fit (*n.*). The tightness or looseness between the mating surfaces of mating parts. See Secs. 7-33 and 7-34.

Flange (*n.*). The projecting rim, or edge, of a part that serves to strengthen it or permit connection to another part.



Flange

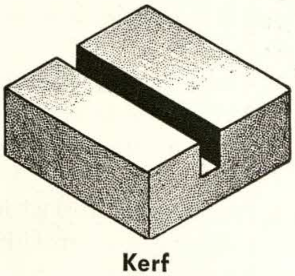
Forge (*v.*). To shape hot or cold metal by hand or machine. See Fig. 6-20.

Galvanize (*v.*). To coat with lead or zinc to prevent rusting.

Graduate (*v.*). To mark off into measured intervals.

Grind (*v.*). To bring to a smooth finish by means of an abrasive. See Fig. 6-11.

Kerf (*n.*). A channel or groove.



Kerf

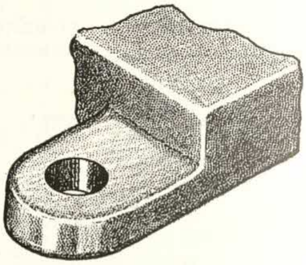
Key (*n.*). A wedge of any desired shape which prevents movement circumferentially between a hub and shaft. See Fig. 12-33.

Keyway or key seat (*n.*). The groove or slot in which the key is placed. The key slides in a keyway and rests in a key seat. See Fig. 12-34.

Knurl (*v.*). To roughen or score a cylindrical surface so that it may be more easily gripped by the hand. See Fig. 7-30.

Lap (*v.*). To finish or polish with cloth, leather, or wood impregnated with abrasive material. See Sec. 6-21.

Lug (*n.*). A projecting "ear" which permits attaching one part to another. See also Fig. 8-26.



Lug

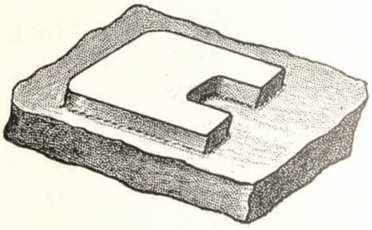
Malleable casting (*n.*). Usually an intricate shaped part, made up of heavy and thin sections, that has been strengthened and toughened by annealing.

Mill (*v.*). To machine with rotating cutters on a milling machine. See Fig. 6-8.

Neck (*n.*). A groove cut into a shaft; often located at or near the point of diameter change. See Fig. 7-29*A*.

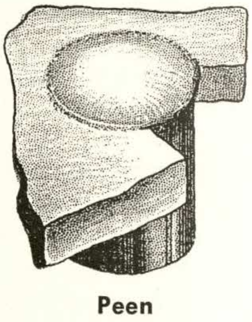
Pack-harden (*v.*). To carburize and caseharden.

Pad (*n.*). A low projection, usually rectangular in shape.



Pad

Peen (*v.*). To expand or bend metal with the round head of a peen hammer.



Peen

Pickle (*v.*). To clean castings and forgings by immersion in a weak sulfuric acid bath.

Plane (*v.*). To machine a flat surface on a planer. See Fig. 6-10.

Plate (*v.*). To coat a metal with a thin layer of another.

Polish (*v.*). To smooth and give luster to a surface by use of a very fine abrasive.

Punch (*v.*). To perforate with a nonrotating tool.

Ream (*v.*). To smooth or slightly enlarge a hole by the use of a fluted rotating tool of the required diameter. See Fig. 6-4.

Rivet (*v.*). To fasten together with rivets. See Fig. 12-36.

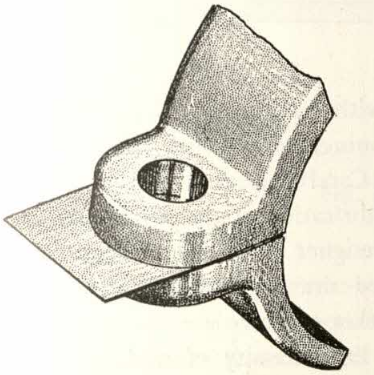
Round (*n.*). A rounded external corner at the intersection of two surfaces. See Fig. 3-14.

Sandblast (*v.*). To clean a surface with sand blown through a nozzle under extremely high pressure.

Shape (*v.*). To machine a surface with a shaper. See Fig. 6-9.

Shear (*v.*). To cut off bar metal or sheet iron with a two-bladed shearing tool. See Fig. 6-13.

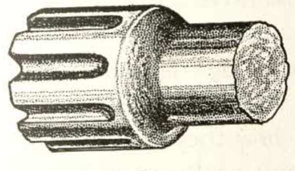
Shim (*n.*). A thin piece of metal placed between surfaces for purposes of adjustment.



Shim

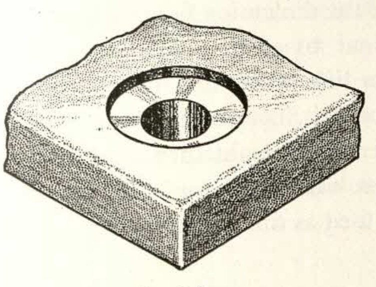
Spin (*v.*). To shape sheet metal into a desired shape by forcing it against the shaping tool as it revolves.

Spline (*v.*). A long keyway.



Splines

Spotface (*v.*). To clean or indent a round finish on a hole to permit accurate seating of the head of a fastener. See also Fig. 6-4.



Spot face

Spot-weld (*v.*). To weld in spots by means of electrodes employed in the electric-resistance-welding processes. See Fig. 6-19.

Steel casting (*n.*). A casting of molten steel of the desired carbon content and requiring no further mechanical working.

Swage (*v.*). To shape or form metal by pressure or hammering with the aid of an anvil known as a "swage block."

Sweat (*v.*). To join together by placing solder between the pieces and applying heat.

Tack weld (*n.*). A weld consisting of short and intermittent sections.

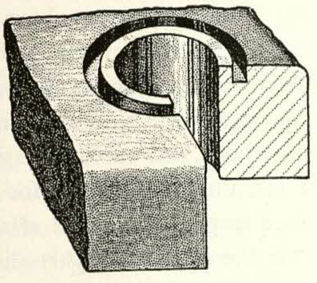
Tap (*n.*). A tapered tool with fluted cutting edges for forming an internal thread. See Fig. 6-4.

(*v.*). To cut internal threads with a tap.

Temper (*v.*). To change the hardness of steel by reheating and permitting it to cool.

Template (*n.*). A pattern that is used as a guide for tracing shapes, locating holes, etc.

Trepan (*v.*). To cut an annular groove around a hole.

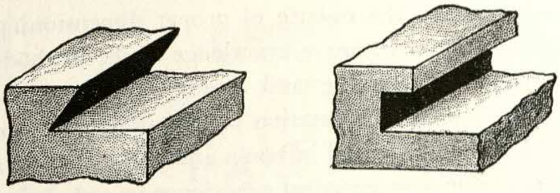


Trepan

Tumble (*v.*). To clean and smooth castings through contact with each other while being spun in a drum containing scraps of other metals.

Turn (*v.*). To machine on a lathe. See Fig. 6-5.

Undercut (*v.*). To machine a part so as to provide an overhanging edge.



Undercut

Upset (*v.*). A forging operation employed to enlarge a diameter or form a shoulder on a bar.

Weld (*v.*). To join together by heating and pressing or by adding fusing material at the joint. See Fig. 6-18.

Chapter 7

DIMENSIONING

In our treatment of engineering drawing, we have thus far been concerned primarily with means of representing the shape of an object. A description of shape is valueless, however, without proper and complete indication of size. The shopworker must know the exact width, height, and depth of a piece, the diameters and precise location of holes or shafts, the amount of tolerance for machining, and many other important details relating to the manufacture of the particular part shown in the drawing. Such information should be supplied by the draftsman on the drawing and is called *dimensioning.*

The shopworker is required to follow the instructions that appear on his working drawing and is limited to the tools and other facilities that are available to him in the shop. Therefore, the draftsman, as well as the engineer, should become thoroughly familiar with the materials used and the fundamental processes of construction and manufacturing, for the essence of proper dimensioning stems from an intimate knowledge of the methods employed in making and assembling the parts. Much valuable information on manufacturing operations can be found in books and periodicals, but observation and practical experience in a shop are an even better source.

If the draftsman keeps in mind the shop processes that will be used in the manufacture of a part, its machining requirements, and its manner of assembly with mating parts, he may, through skilled dimensioning, reduce the number of operations needed. Careful dimensioning will also help to ensure fabrication of the piece exactly as intended by the designer and the draftsman. A properly dimensioned drawing should make it possible for each worker to complete his own specialized task without the necessity of making calculations, attempting to scale the drawing, or calling on his associates for suggestions and assumptions concerning missing information or dimensions. A common error of the beginning draftsman is to show the dimensions he used in making his drawing instead of those necessary for the fabrication of the part.

7-1. Dimensioning elements: The dimension line. Figure 7-1 illustrates the basic dimensioning elements and how they are commonly used. Since dimensions must not be placed on the outlines of the object being drawn, distances or angles that are to be measured are indicated by dimension lines. The dimension line is light and firm and is broken at or near the center to allow for the insertion of the dimension figures. In structural practice, and at times in architectural drawing, the dimension line is left unbroken, while figures are placed above it. Dimension lines should not cross each other, nor should they cross extension lines, unless absolutely necessary. Center lines should never be used as dimension lines.

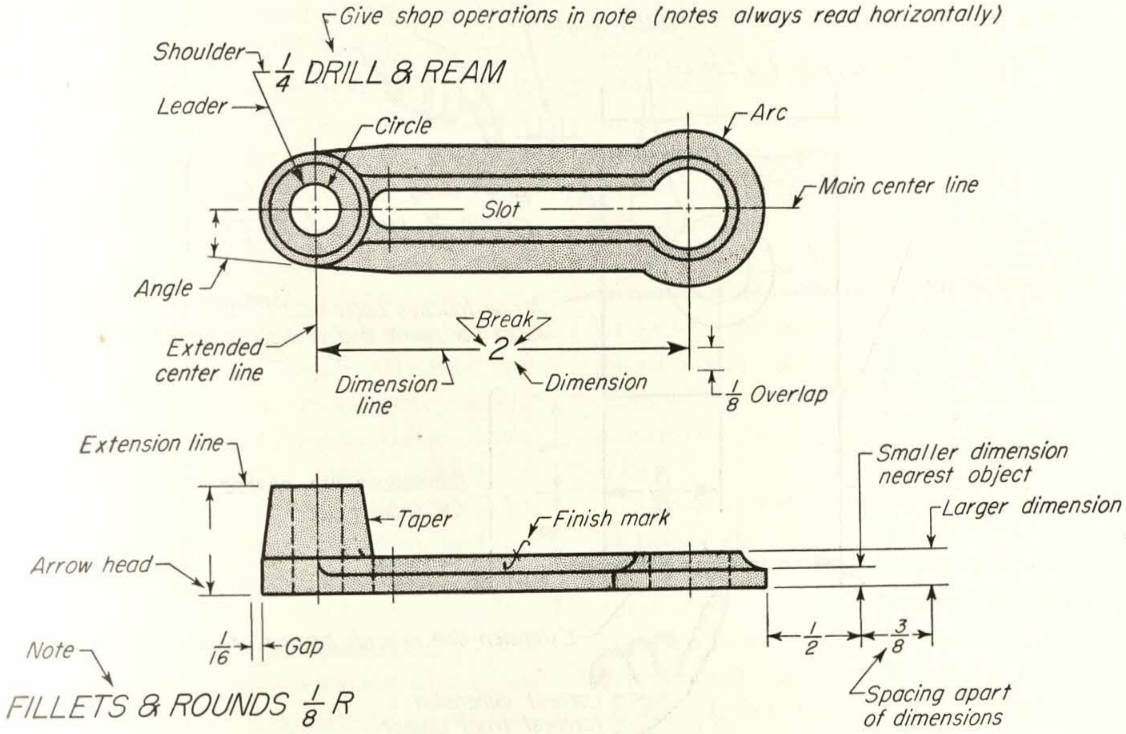


Fig. 7-1. Dimensioning elements.

7-2. Extension lines. Extension lines are thin unbroken lines used to indicate the extremities of the distance measured by the dimension line. An extension line does not touch the outline of the feature from which it extends but starts about $\frac{1}{16}$ in. from it and reaches to a point about $\frac{1}{8}$ in. beyond the last dimension line. Extension lines may cross an outline line of the object or another extension line wherever necessary (see Fig. 7-32, for example). Whenever practicable, extension lines should extend beyond the outlines of the part to allow for dimensioning outside the view (see Fig. 7-38*A*). Center lines representing the axes of symmetrical features, holes, etc., may be extended as necessary to serve as extension lines.

7-3. Arrowheads. The dimension line terminates in arrowheads that touch the extension lines. An arrowhead should be drawn freehand, with two concave strokes made in the direction of the point (see Fig. 7-2). The length may vary from $\frac{1}{8}$ in. on small drawings to $\frac{3}{16}$ in. on larger ones. The width of the base of the arrowhead should be approximately one-third the length. Arrowheads should be drawn the same size throughout a drawing, except in restricted spaces, where they may have to be made smaller.

7-4. Dimension figures. The dimension figure is placed in the break of the dimension line, as shown in Fig. 7-2. Note that the numerals in the numerator and denominator of the fraction are smaller than the whole number but that the overall height of the fraction is twice that of the whole number. In general, when all dimensions are given in inches, the inch mark (") is omitted entirely.

7-5. Leaders. The leader is a fine line that extends from a dimension number or note toward the form to which it applies, where it ends in an arrowhead that touches the outline (see Fig. 7-3). At the figure or note end, the leader terminates with a shoulder about $\frac{1}{8}$ in. long which should lie even with an imaginary midline drawn through

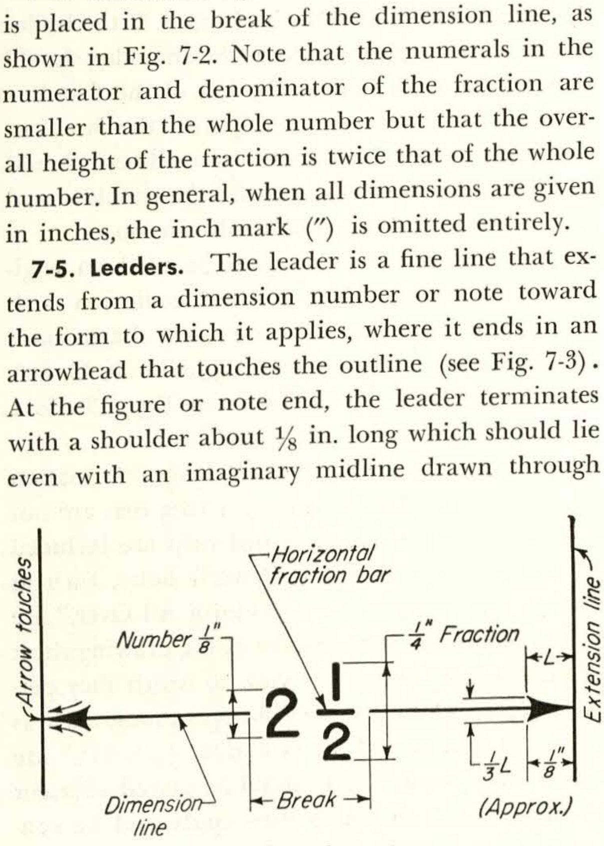


Fig. 7-2. A dimension.

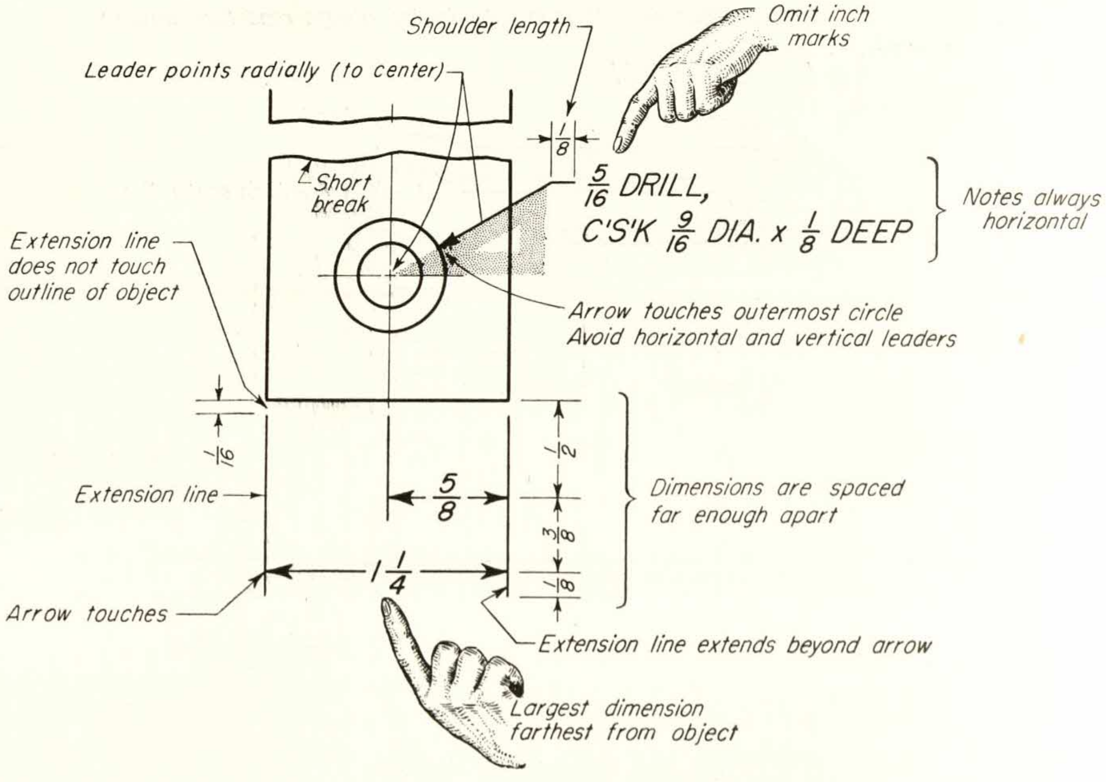

Shoulder length
Leader points radially (to center)
Omit inch marks
1/8
Short break
5/16 DRILL,
C'S'K 9/16 DIA. x 1/8 DEEP
Notes always horizontal
Extension line does not touch outline of object
Arrow touches outermost circle
Avoid horizontal and vertical leaders
1/16
Extension line
5/8
1/2
3/8
1/8
Dimensions are spaced far enough apart
1 1/4
Arrow touches
Extension line extends beyond arrow
Largest dimension farthest from object

Fig. 7-3. Dimensioning elements.

the figure or note and 1/16 in. from it. If the leader extends from a lengthy note, the shoulder should start at the midheight at the left of the first line or at the midheight at the right of the last line, never from the middle of the note. There should be about 1/16 in. space between the shoulder end of the leader and the note or dimension.

Curved leaders should never be used on engineering drawings. Also, to avoid confusion with lines of the object, leaders are never drawn horizontally or vertically. Instead, angles of 30, 45, 60°, etc., should be used, as shown in Fig. 7-3. As a general rule, leaders should not cross.

7-6. Notes. Instructions and basic information relating to the manufacture of a part that are not put in the title block or record strip are included on the drawing as notes. General notes, such as "Fillets and Rounds 1/8" or "Finish All Over," are placed along the lower border of the drawing sheet or are centered below the view to which they pertain. Notes relating to specific operations, such as "1/4 Drill and Ream" or "Chamfer 1/8 × 45°," are called "local notes" and should be placed adjacent to the features to which they apply and be connected to them by leaders. Notes should always be placed to read horizontally. The width of the letter strokes of a note or dimension should be slightly finer than the outline of the object. Figure 7-19 shows a number of typical notes used in dimensioning holes.

7-7. Finish marks. In dimensioning a drawing, the draftsman should mark all surfaces of a casting or forging that are to be machined. In addition to indicating the machining operation, finish marks suggest to the patternmaker where to provide extra metal on the rough casting or forging to allow for the finishing process. Figure 7-4 shows the two types of finish marks in use and illustrates the principles of their construction and placement. The older one, *f*, is still used by some of the larger manufacturing companies. The mark V is now more common, however, and is the one recommended by the ASA. The finish mark is always placed on the edge view of the surface to be machined and is indicated in all views where the surface shows as a line, even if the line is a hidden line. In the case of the V mark, the point touches the surface while the wings are in the air (away from the object).

If required, a code number may be added to indicate the quality of finish desired. The ASA has developed a Standard that lists recommended symbols and specifications for indicating specific surface quality and finish. Part of this Standard is reproduced in Standards for Drawings and Drafting Room Practice (ASA Z14.1—1946). At the end of this chapter, some of the uses for the V symbol when employed in connection with surface-quality control are explained.

When a piece is to be finished all over, the letters "FAO" or the words "Finish All Over" are used and the finish marks are omitted entirely. Only surface-quality-control finish marks are shown (when required) on rolled stock (shafts) or on drilled, reamed, or bored holes in highly finishing operations. The ordinary finish mark is omitted from these surfaces. See Sec. 7-45 and Fig. 7-52.

7-8. Fractional and decimal dimensions. There are three basic systems for giving size dimensions that are in common use in industry: (1) the fractional system, (2) the combined fractional and decimal system, and (3) the complete decimal system.

The fractional system is used in manufacturing plants where the accuracy need be only to $\frac{1}{64}$ in. Dimensions are given in units and fractional parts of an inch, such as $2\frac{3}{4}$, $3\frac{1}{8}$, $\frac{29}{32}$, $\frac{11}{64}$ in. In some industries, dimensions greater than 72 in. are given in feet and inches, for example, 9′-7″ or 12′-0″.

Ordinarily, it is impractical to use fractions smaller than $\frac{1}{64}$ in., and so when greater accuracy is required, dimensions are given in decimal parts of an inch, for example, 2.36 or 3.120 in. The combined system therefore employs decimal dimensions where accuracy is important and fractional dimensions for less critical dimensions (see Fig. 7-5*A*).

The complete decimal system, in which all dimensions are given as decimal parts of an inch, has gained wide usage. This system not only assures accuracy and uniformity but also facilitates computations and limit dimensioning. The ASA recommends that two-place even decimals (such as .02, .10, .84) be used wherever possible (see Fig. 7-5*B*). The advantage of an even two-place decimal (for instance, a diameter of .50) lies in the fact that it results in a two-place decimal when halved

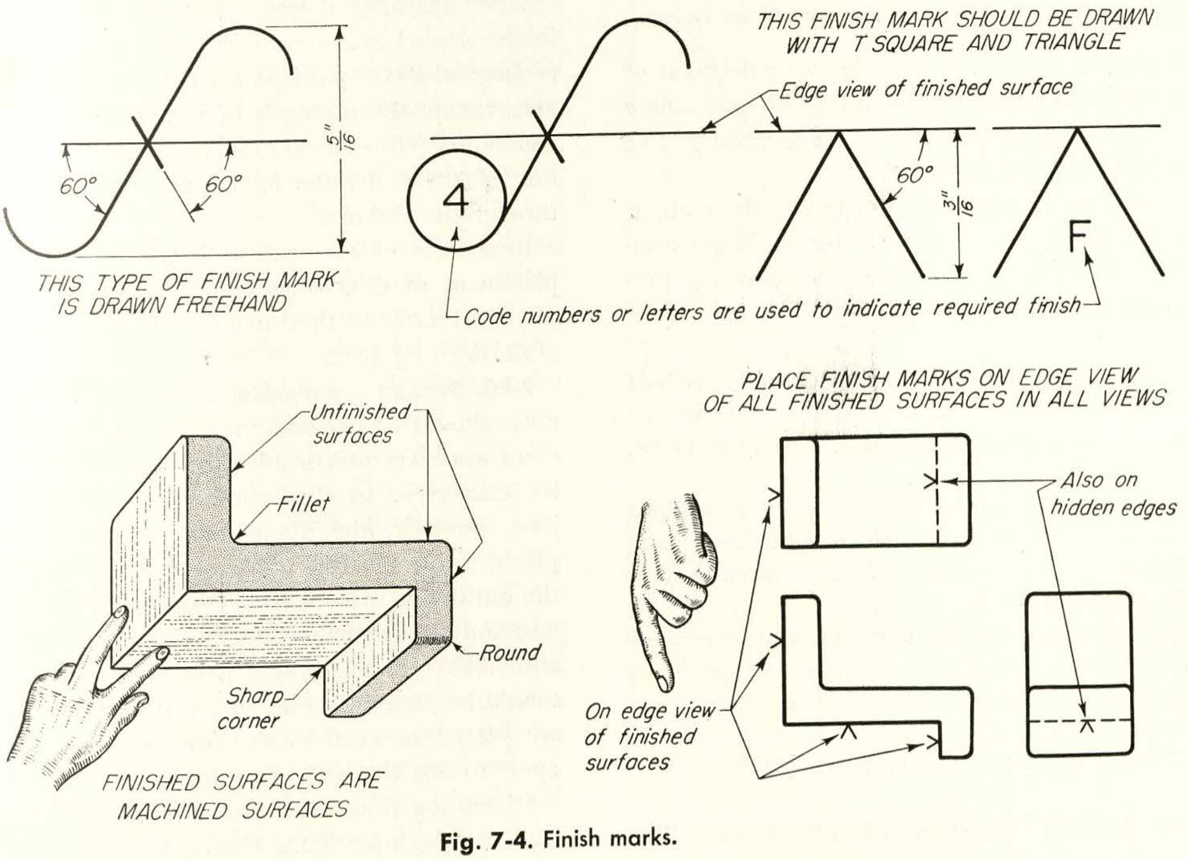

60°
60°
5″/16
THIS TYPE OF FINISH MARK IS DRAWN FREEHAND
4
THIS FINISH MARK SHOULD BE DRAWN WITH T SQUARE AND TRIANGLE
Edge view of finished surface
60°
3″/16
F
Code numbers or letters are used to indicate required finish
Unfinished surfaces
Fillet
Round
Sharp corner
FINISHED SURFACES ARE MACHINED SURFACES
PLACE FINISH MARKS ON EDGE VIEW OF ALL FINISHED SURFACES IN ALL VIEWS
Also on hidden edges
On edge view of finished surfaces

Fig. 7-4. Finish marks.

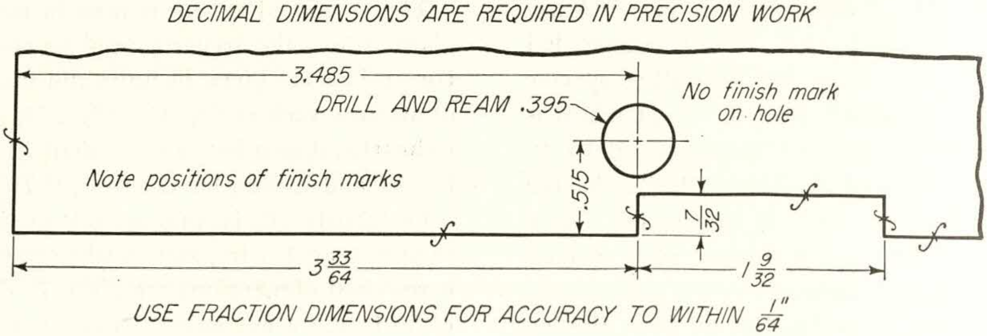

DECIMAL DIMENSIONS ARE REQUIRED IN PRECISION WORK
3.485
DRILL AND REAM .395
No finish mark on hole
Note positions of finish marks
.515
7/32
3 33/64
1 9/32
USE FRACTION DIMENSIONS FOR ACCURACY TO WITHIN 1/64"

Fig. 7-5A. Use of fractional and decimal dimensions.

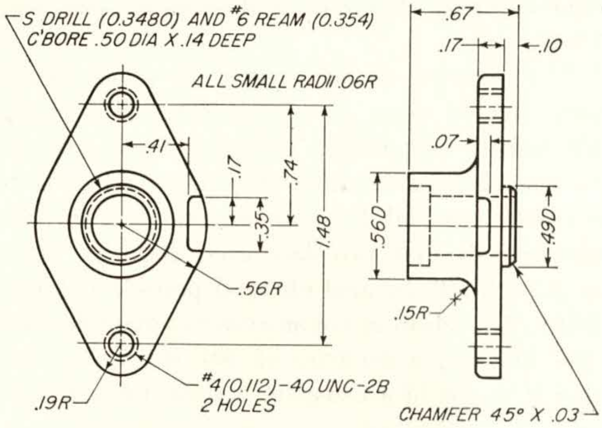


Fig. 7-5B. Decimal dimensioning—two-place system.

(.25 for the radius). Odd decimals or decimals of three or more places may of course be used where extremely precise dimensions are necessary (see Figs. 7-41, 7-42, and 7-44, also).

In converting common fractions to decimals, it is often necessary to round off the significant decimal places. The ASA suggests the following procedure for rounding off decimals:

> When the figure beyond the last figure to be retained is less than 5, the last figure retained should not be changed. *Example:* 3.46325, if cut off to three places, should be 3.463.
>
> When the figures beyond the last place to be retained amount to more than 5, the last figure retained should be increased by 1. *Example:* 8.37652, if cut off to three places, should be 8.377.
>
> When the figure beyond the last place to be retained is exactly 5 with only zeros following, the preceding number, if even, should be unchanged; if odd, it should be increased by 1. *Example:* 4.365 becomes 4.36 and 4.375 becomes 4.38 when cut off to two places.

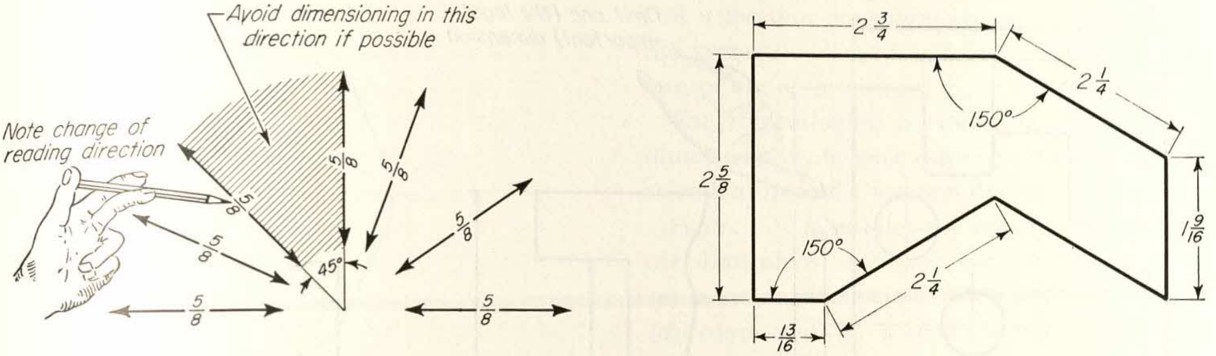
7-9. Reading direction of dimensions. The ASA has approved two methods of placing dimensions on a drawing: the aligned system and the unidirectional system (see Fig. 7-6). In the aligned system, the dimension figures are always placed at right angles to the dimension line and are orientated so that they are readable either from the bottom or from the right-hand side of the drawing. In the unidirectional system, the dimension figures are arranged so that they may invariably be read from the bottom of the drawing. This system was devised to facilitate reading large drawings and is used extensively in the aircraft and automotive industries.

When the aligned system is used, dimensioning in the shaded area shown in the figure should be avoided wherever possible, since dimensions in this area violate the principle of bottom or right-side readability. Note the change in the reading direction of the dimension figures as they are rotated through the 180° arc.

Regardless of the system that is used for the placement of dimension figures, notes should always be located so that they read from the bottom of the drawing sheet.

7-10. Placing dimensions. Dimensions and notes should be placed outside the outlines of the piece whenever practicable (see Figs. 7-3 and 7-5*B* for example). In dimensioning complicated objects, however, the dimensions may have to be placed on or near the features, thus falling within the outline of the object but adding to the directness and clarity of the presentation (see Figs. 7-26 and 7-38*B*). In so far as it is possible, dimensions should be placed between views. When dimensions are placed between views, however, they should apply to one view only (see Fig. 7-7).

Dimension lines should be located about ½ in. from the outlines of the object. In a group of dimensions, the smallest is always placed nearest


Avoid dimensioning in this direction if possible
Note change of reading direction
5/8
5/8
5/8
5/8
5/8
5/8
5/8
5/8
45°
2 3/4
2 1/4
150°
2 5/8
1 9/16
150°
2 1/4
13/16

IN THE ALIGNED SYSTEM THE FIGURES ARE ALIGNED PERPENDICULAR TO THE LEADERS AND ARROWS

IN THE UNIDIRECTIONAL SYSTEM ALL FIGURES ARE READ FROM THE BOTTOM OF THE DRAWING SHEET

Fig. 7-6. Reading direction for dimensions.

the piece and is followed by progressively larger dimensions uniformly spaced at a minimum of 3/8 in. apart (Fig. 7-3). This procedure minimizes the likelihood of crossed extension lines.

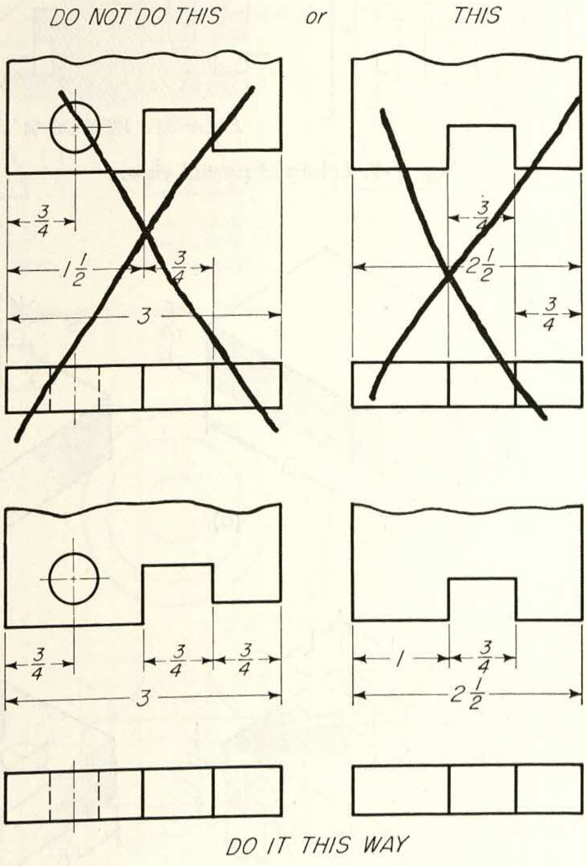
Continuous dimensions are preferable to staggered dimensions because of the ease with which they may be read (see Fig. 7-8). Staggered dimensions (Fig. 7-8) may sometimes be necessary, however, to facilitate proper placement of figures and notes.

As a general rule, dimension figures should be located at the center of the dimension line except when another line interferes. If a number of parallel dimension lines occur together, dimension figures are staggered for readability (see Fig. 7-8).

Dimensions should never be crowded into limited spaces. The use of notes is often a suitable way to avoid crowding of dimensions. If notes are not appropriate, a portion of the part may be enlarged as a separate partial view (Fig. 7-9), or the methods shown in Fig. 7-10 may be used.

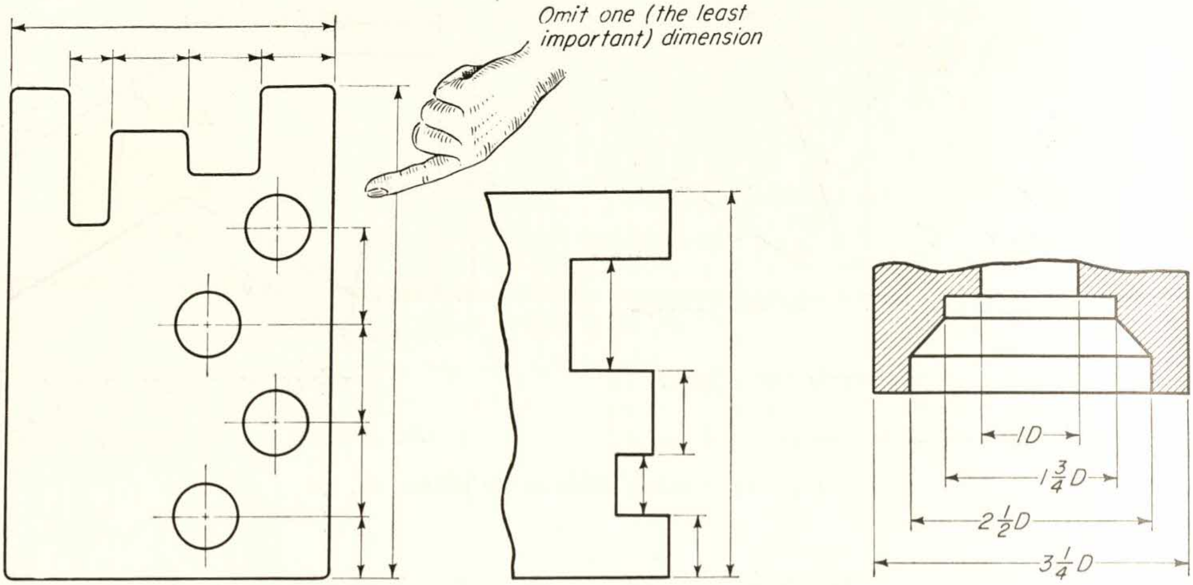
Dimensioning to hidden lines should be avoided as far as possible. The required dimensions may be placed in other existing views. If these are not suitable, additional ones (partial or sectioned views) should be prepared for the purpose.

7-11. The theory of dimensioning. No matter how complicated in appearance an engineering form may be, it can be broken down into a group of assembled simple geometric shapes such as prisms, cylinders, cones, pyramids, spheres, etc., in their positive or negative states. (A shaft is a positive cylinder; a hole is a negative cylinder; etc.) It is then a relatively simple matter to dimension these geometric forms in a manner that will show their individual sizes and their location relative to each other. The dimensions of the contours of each geometric shape show its size and are known as *size dimensions.* The dimensions that locate these geometric shapes in relation to each other are



Dimensions should be placed on, and refer to, one view

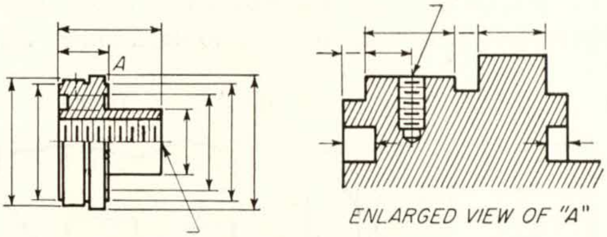
Fig. 7-7. Dimensions apply to one view only.



Omit one (the least important) dimension

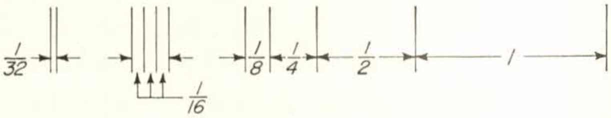
CONTINUOUS DIMENSIONS STAGGERED DIMENSIONS STAGGERED FIGURES

Fig. 7-8. Placing dimensions.



ENLARGED VIEW OF "A"

Fig. 7-9. Enlarged partial view.



NEVER CROWD DIMENSIONS IN LIMITED SPACES
ALWAYS MAKE FIGURES LEGIBLE

Fig. 7-10. Dimensioning in limited spaces.

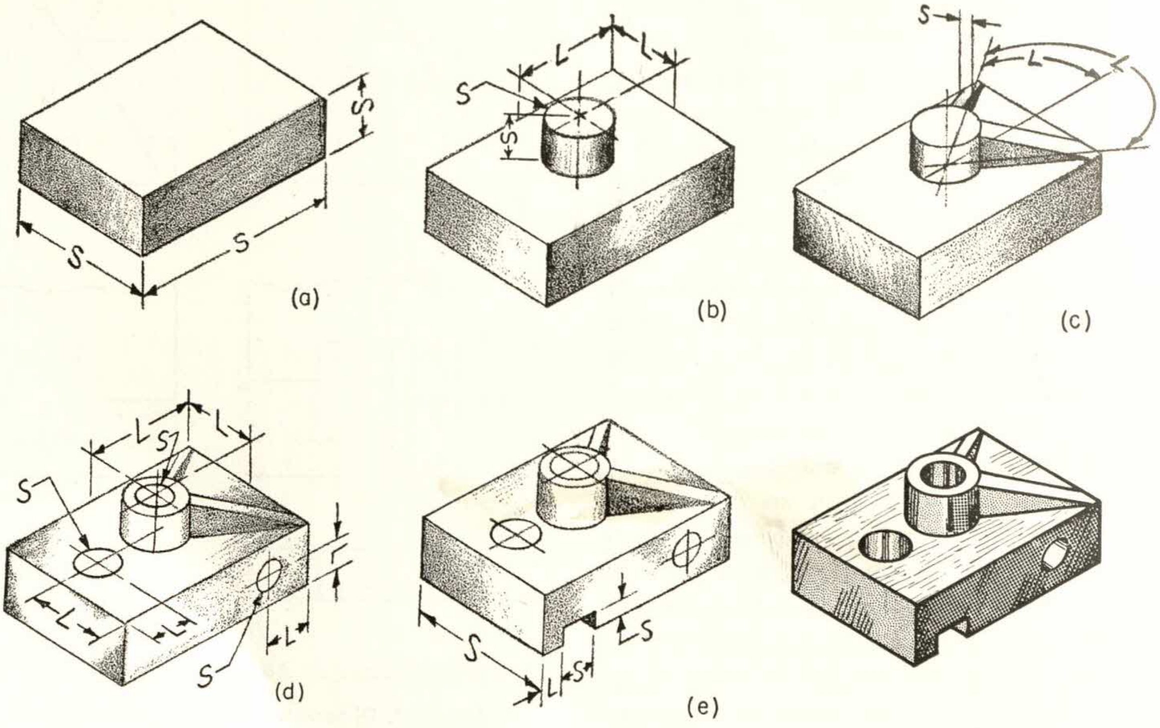


Fig. 7-11. Size and location dimensions.

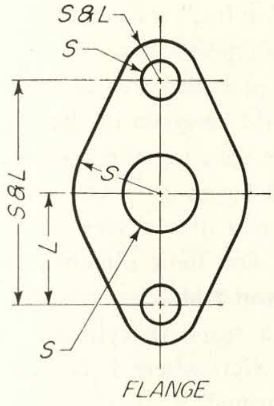


Fig. 7-12. Size and location given by one dimension.

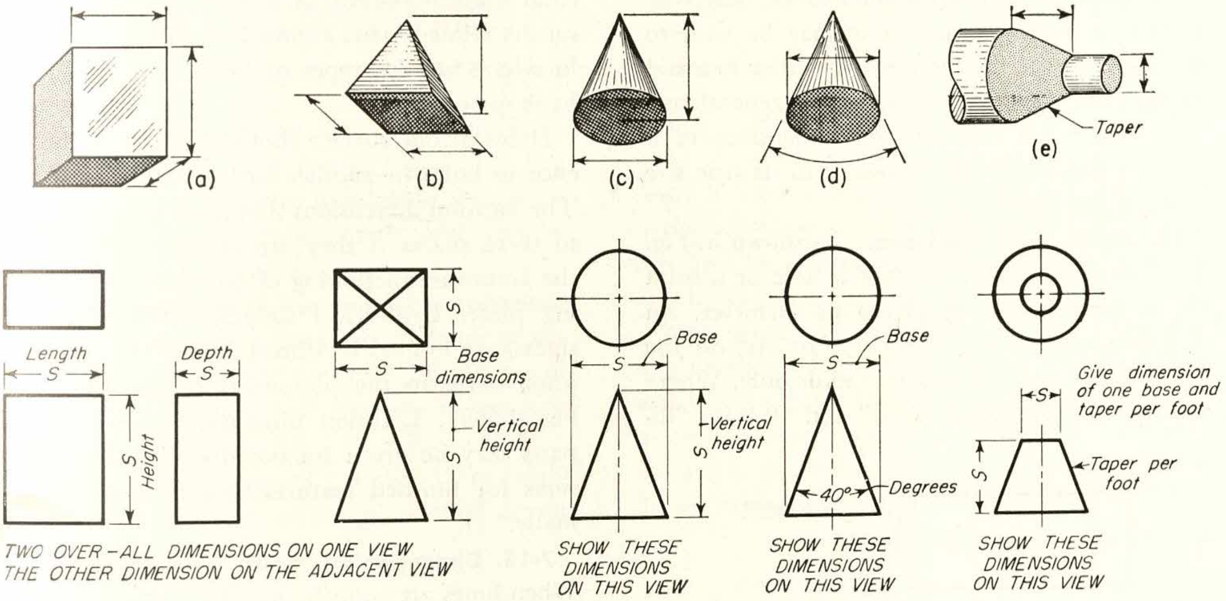

(a)
(b)
(c)
(d)
Taper
(e)
Length
S
Depth
S
S
Height
S
S
Base dimensions
Vertical height
S
Base
S
Vertical height
Base
S
40°
Degrees
S
Give dimension of one base and taper per foot
S
Taper per foot
TWO OVER-ALL DIMENSIONS ON ONE VIEW
THE OTHER DIMENSION ON THE ADJACENT VIEW
SHOW THESE DIMENSIONS ON THIS VIEW
SHOW THESE DIMENSIONS ON THIS VIEW
SHOW THESE DIMENSIONS ON THIS VIEW

Fig. 7-13. Size dimensions of common geometric forms.

known as *location dimensions.* The two types of dimensions cannot always be sharply distinguished, however, since in some instances size dimensions also serve as location dimensions.

7-12. Size dimensions and location dimensions. The geometric breakdown of a simple machine form is shown in Fig. 7-11. In the figure, *S* indicates a size dimension and *L* a location dimension. In (*a*), the dimensions shown give the size of the prism. In (*b*), the dimensions give the size of the cylinder and its location on the prism. In (*c*), the dimensions indicate the size and locations of the ribs. The size and location dimensions given in (*a*), (*b*), and (*c*) interest the worker who will make the pattern for the casting. The size and location dimensions of the holes and slot in (*d*) and (*e*) are necessary for the machine-shop worker who will fashion these with the proper tools. Note that a location dimension serves to locate the entire geometric element and not merely a side, surface, or line of the element.

The dimensioning of the flange in Fig. 7-12 illustrates how, in some cases, one dimension serves as both a size and a location dimension.

Figure 7-13 illustrates the manner in which the size dimensions of certain basic forms are given: (*a*) a rectangular prism, (*b*) a pyramid, (*c*) and (*d*) cones, and (*e*) a cone frustum illustrating a taper. The manner in which the torus (a round ring or protuberance) and the sphere are dimensioned is shown in Fig. 7-14. The dimensioning of

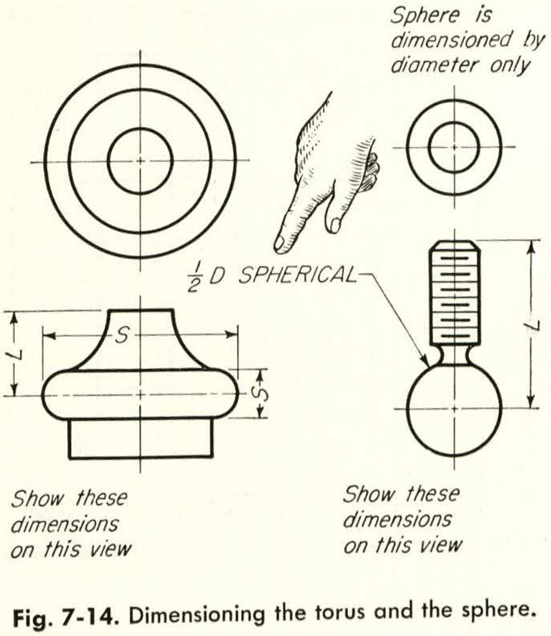

Sphere is dimensioned by diameter only
½ D SPHERICAL
S
L
S
L
Show these dimensions on this view
Show these dimensions on this view

Fig. 7-14. Dimensioning the torus and the sphere.

a spherical end is shown in Fig. 7-15.

Over-all dimensions (the principal size dimensions that give the entire width, height, and thickness of the object) should always be shown outside (or beyond) all other dimensions, avoiding as far as possible the crossing of extension lines. Over-all dimensions should be placed so that two appear on one view and the third on an adjacent view.

7-13. The principle of contour dimensioning. Typical features of objects such as holes, round ends, angles, slots, etc., may be seen and dimensioned more clearly in views where their contour shapes appear, rather than in other views where they may appear as hidden lines or be otherwise obscured. In some cases, a note may be used to dimension a single hidden detail in order to avoid drawing extra views. Nevertheless, the general rule is to give the size and location dimensions of a feature in the view which shows it in its true size and shape (see Fig. 7-16).

7-14. Shafts, holes, and arcs. As shown in Fig. 7-17, a complete circle, whether a hole or a solid shaft, is dimensioned by giving its diameter. An incomplete circle, such as a curve or arc, on the other hand, is dimensioned by radius only. Where necessary, the abbreviations "D" and "R," for "diameter" and "radius," respectively, should be used to avoid misinterpretations.

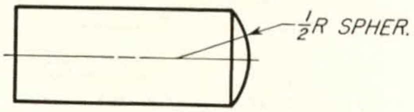


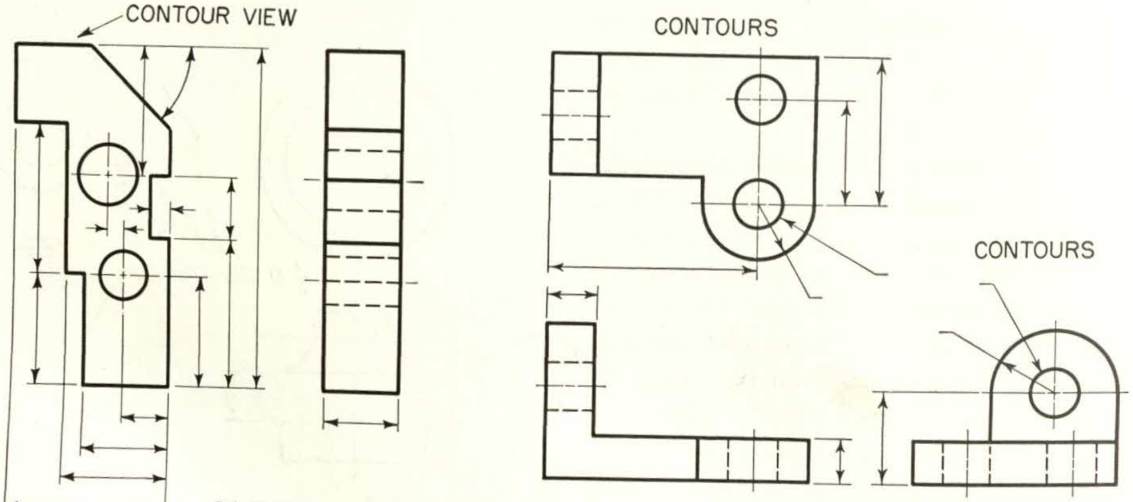
Fig. 7-15. Dimensioning of spherical ends.

The length and diameter of a positive cylinder (a shaft) should be given in the view where these dimensions are seen together (see Fig. 7-18). Simple cylindrical forms may be drawn and dimensioned completely in one view (see the right side of Fig. 7-17). For limit dimensioning of a shaft, see Figs. 7-42 and 7-44.

Dimension a negative cylinder (a hole) completely in the view where it is seen as a circle. If a hole goes through a piece, which is usually the case, the depth of the hole is not given in the circular view inasmuch as this information appears on the related view. Figure 7-19 shows the manner in which various types of holes are dimensioned by shop notes.

Holes in one surface should be located in reference to holes in another surface (see Fig. 7-20*a*). The location dimensions should be given decimally to three places if they are actually important to the accurate functioning of one part with its mating piece. Cylindrical shapes, whether holes or shafts, are located by dimensioning to their center lines, never to the perimeters of the circles (see Fig. 7-20*b*). Location dimensions for unfinished parts may be given fractionally. Location dimensions for finished features should be given decimally.

7-15. Dimensioning holes on a bolt circle. When holes are *equally spaced* in a circular flange, one hole should be located on either the vertical or



DIMENSION SIGNIFICANT FEATURES IN VIEW THAT SHOWS THEIR TRUE SHAPES

Fig. 7-16. Principle of contour dimensioning.

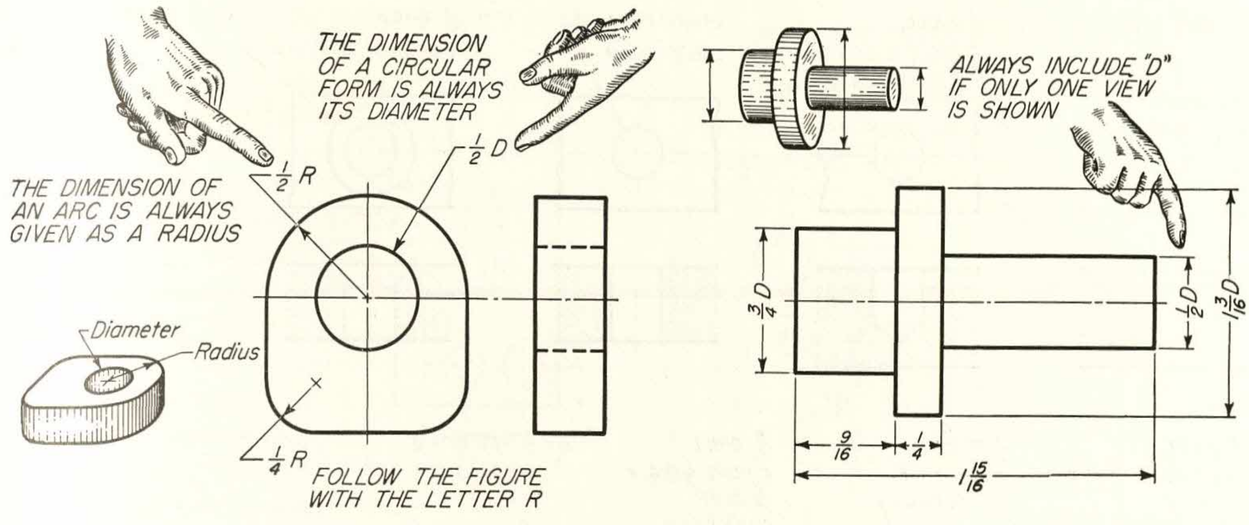

THE DIMENSION OF A CIRCULAR FORM IS ALWAYS ITS DIAMETER
1/2 D
THE DIMENSION OF AN ARC IS ALWAYS GIVEN AS A RADIUS
1/2 R
Diameter
Radius
1/4 R
FOLLOW THE FIGURE WITH THE LETTER R
ALWAYS INCLUDE "D" IF ONLY ONE VIEW IS SHOWN
3/4 D
1/2 D
1 3/16 D
9/16
1/4
1 15/16

Fig. 7-17. Dimensioning arcs and circles.

the horizontal main center line. Then the holes may be dimensioned as shown in Fig. 7-21*a*. The diameter dimension of the bolt circle should always be given in the circular view and may be added to the dimension note.

7-16. Locating holes by rectangular coordinates. When extremely precise location dimensions for holes are required, locate the holes by the use of rectangular coordinates, and give the dimensions as decimals (see Fig. 7-21*b*).

7-17. Unequally spaced holes. Unequally spaced holes may be located by the method shown in Fig. 7-22. One hole on the bolt circle is located from one of the main center lines (if one is not already located on a center line) by giving the angle in degrees; then the other holes are located from the first hole by angular dimensions. These holes may also be located according to Sec. 7-16.

7-18. Arcs and round-end shapes. An arc is dimensioned by giving the radius of the circle of which it is a part. The center of the circle is shown by crossed lines from which the dimension line for the arc is extended. The dimension line is always drawn at an angle and has an arrowhead only at

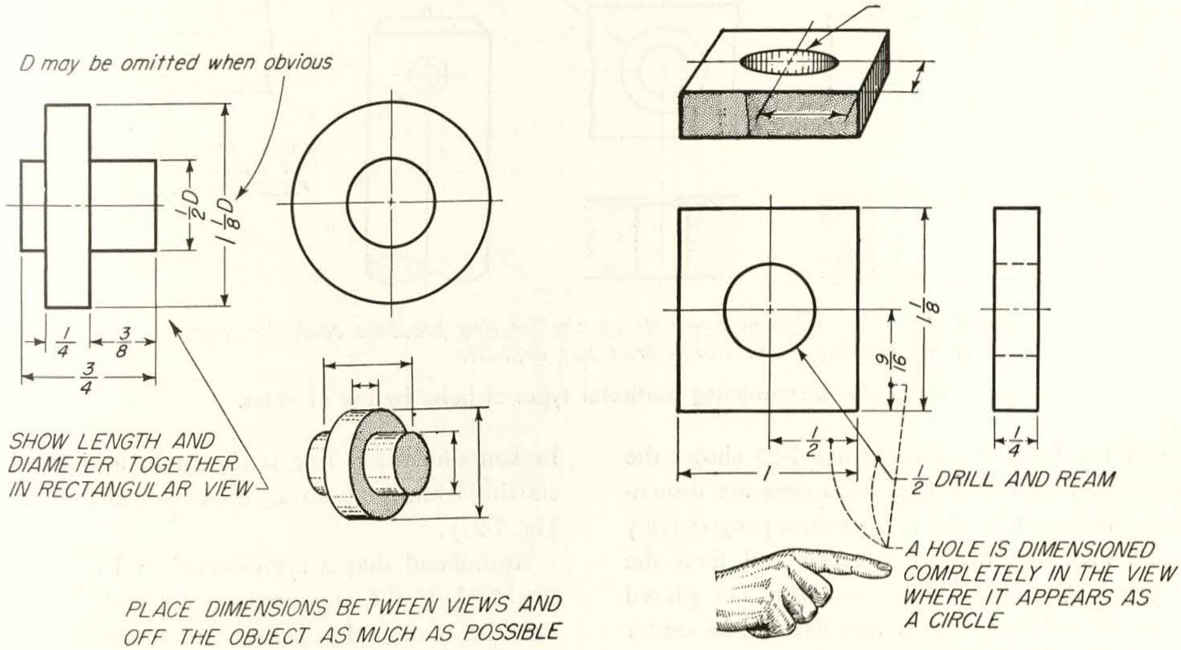
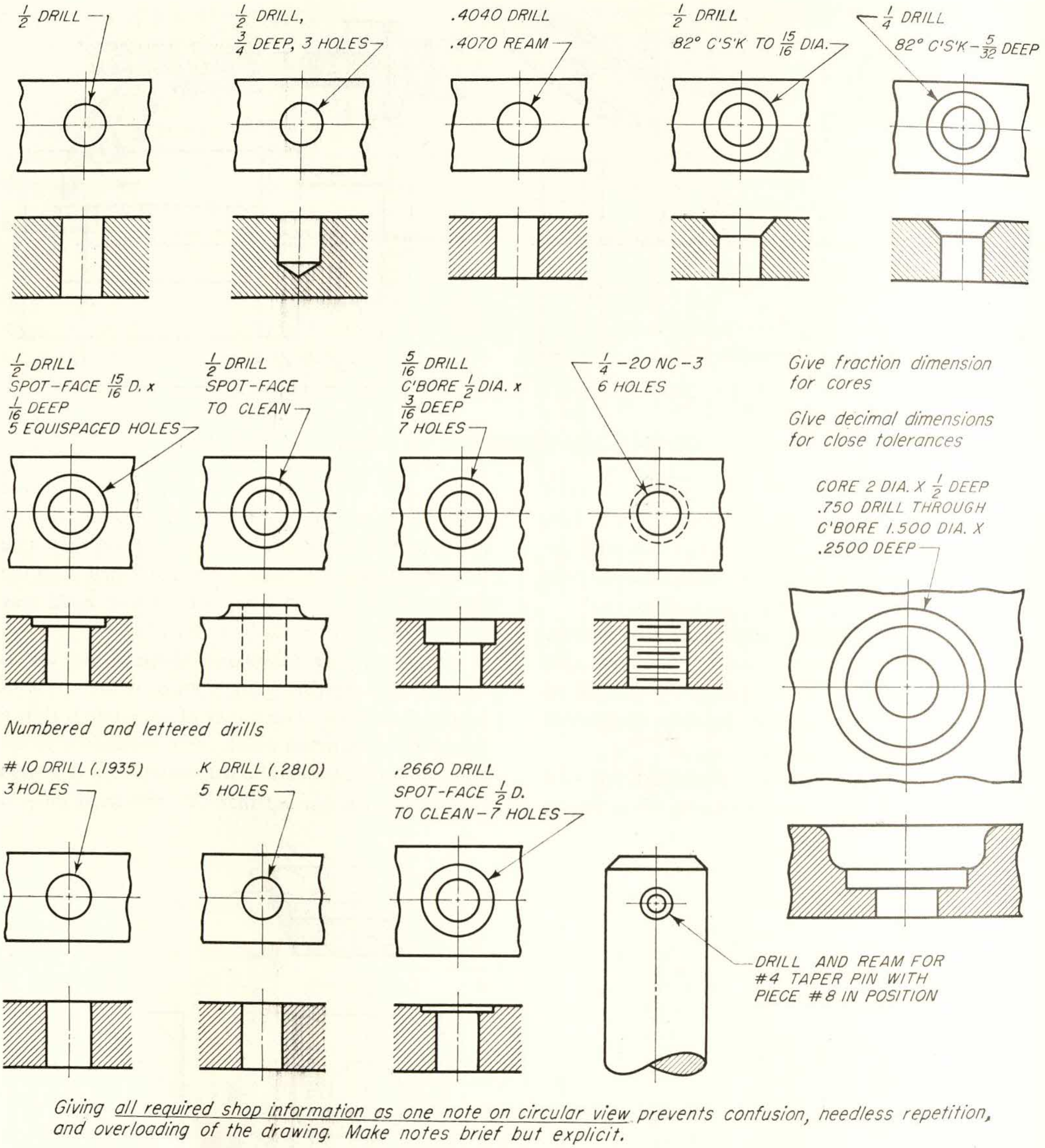

D may be omitted when obvious
1/2 D
1 1/8 D
1/4
3/8
3/4
SHOW LENGTH AND DIAMETER TOGETHER IN RECTANGULAR VIEW
PLACE DIMENSIONS BETWEEN VIEWS AND OFF THE OBJECT AS MUCH AS POSSIBLE
1 1/8
9/16
1/2
1
1/4
1/2 DRILL AND REAM
A HOLE IS DIMENSIONED COMPLETELY IN THE VIEW WHERE IT APPEARS AS A CIRCLE

Fig. 7-18. Dimensioning a shaft and a hole.


$\frac{1}{2}$ DRILL
$\frac{1}{2}$ DRILL, $\frac{3}{4}$ DEEP, 3 HOLES
.4040 DRILL .4070 REAM
$\frac{1}{2}$ DRILL 82° C'S'K TO $\frac{15}{16}$ DIA.
$\frac{1}{4}$ DRILL 82° C'S'K – $\frac{5}{32}$ DEEP
$\frac{1}{2}$ DRILL SPOT-FACE $\frac{15}{16}$ D. x $\frac{1}{16}$ DEEP 5 EQUISPACED HOLES
$\frac{1}{2}$ DRILL SPOT-FACE TO CLEAN
$\frac{5}{16}$ DRILL C'BORE $\frac{1}{2}$ DIA. x $\frac{3}{16}$ DEEP 7 HOLES
$\frac{1}{4}$ -20 NC-3 6 HOLES
Give fraction dimension for cores
Give decimal dimensions for close tolerances
CORE 2 DIA. X $\frac{1}{2}$ DEEP .750 DRILL THROUGH C'BORE 1.500 DIA. X .2500 DEEP
Numbered and lettered drills
#10 DRILL (.1935) 3 HOLES
K DRILL (.2810) 5 HOLES
.2660 DRILL SPOT-FACE $\frac{1}{2}$ D. TO CLEAN – 7 HOLES
DRILL AND REAM FOR #4 TAPER PIN WITH PIECE #8 IN POSITION

Giving all required shop information as one note on circular view prevents confusion, needless repetition, and overloading of the drawing. Make notes brief but explicit.

Fig. 7-19. Dimensioning particular types of holes by use of notes.

the end touching the arc. Figure 7-23 shows the manner in which arcs of various sizes are dimensioned. Note that, as the arc becomes progressively smaller, first the dimension figure and then the dimension figure and dimension line are placed outside the arc. If an arc is very flat and its center lies outside the boundaries of the drawing, the broken dimension line is shown in a zigzag form starting from the point of the center of the arc (see Fig. 7-27).

Round-end shapes are dimensioned as shown in Fig. 7-24. If the arcs on opposite ends of a piece are the same, the center lines for both arcs should be drawn, but only one arc need be di-

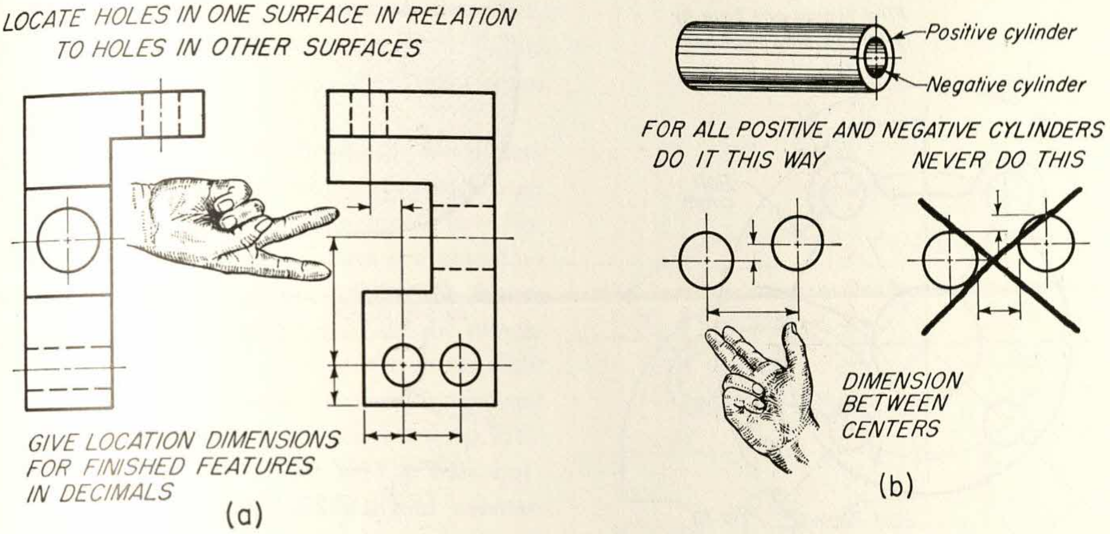

LOCATE HOLES IN ONE SURFACE IN RELATION TO HOLES IN OTHER SURFACES
GIVE LOCATION DIMENSIONS FOR FINISHED FEATURES IN DECIMALS
(a)
Positive cylinder
Negative cylinder
FOR ALL POSITIVE AND NEGATIVE CYLINDERS
DO IT THIS WAY
NEVER DO THIS
DIMENSION BETWEEN CENTERS
(b)

Fig. 7-20. Dimensioning holes.

mensioned. When the radii of the arcs are less than ½ in., the size dimension of the piece is given from end to end; when the radii are ½ in. or more, the size dimension from center to center is given.

Slots are dimensioned according to the methods used in their manufacture. Figures 7-25 and 7-26 show the dimensioning of straight and curved round-end slots. Figure 7-26 also illustrates the size and location dimensions necessary for drawing a piece containing various types of slots. The general note "Fillets and Rounds ⅛" is sufficient dimensioning for all arcs of this size that appear on the object being drawn. See also Sec. 8-28.

7-19. Irregular curves. Irregular curves are always dimensioned in the contour view that shows their true shape. The irregular curve may be broken up into a series of circle arcs, which can then be dimensioned by their radii, much as shown in Fig. 7-27. If the center of a radius falls too far from the drawing, the leader is broken as illustrated. Irregular curves may also be dimensioned by a series of offset dimensions originating in a

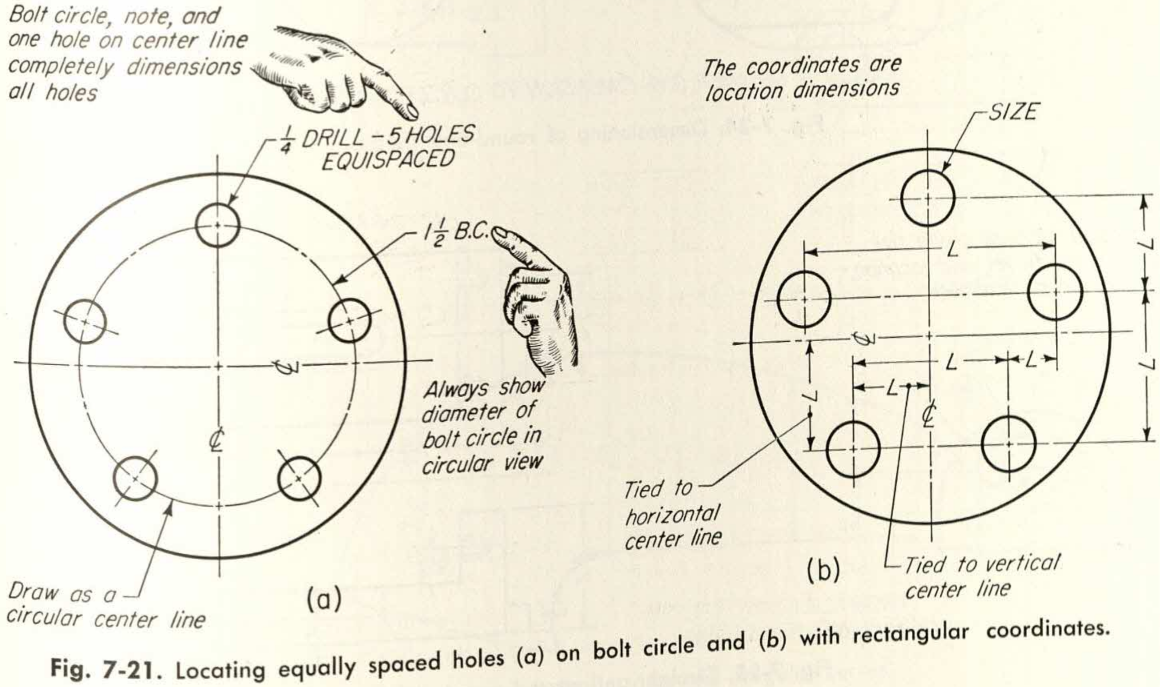
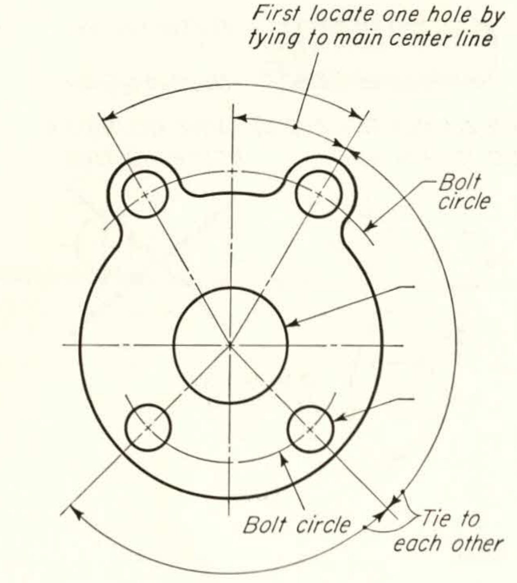

Bolt circle, note, and one hole on center line completely dimensions all holes
1/4 DRILL - 5 HOLES EQUISPACED
1 1/2 B.C.
℄
℄
Always show diameter of bolt circle in circular view
Draw as a circular center line
(a)
The coordinates are location dimensions
SIZE
L
L
L
L
L
L
L
℄
℄
Tied to horizontal center line
Tied to vertical center line
(b)

Fig. 7-21. Locating equally spaced holes (a) on bolt circle and (b) with rectangular coordinates.



UNEQUALLY SPACED HOLES

Fig. 7-22. Dimensioning of unequally spaced holes.

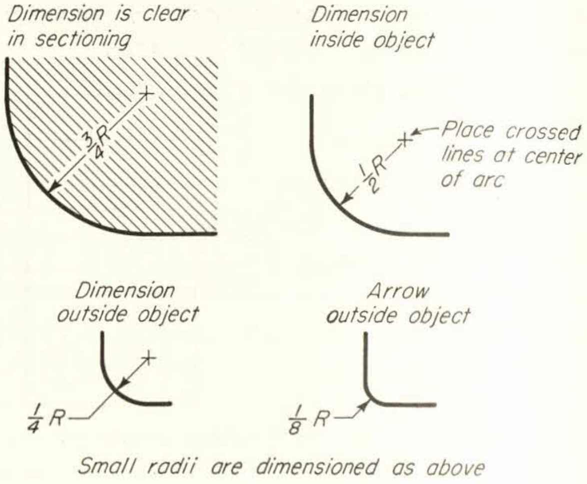

Dimension is clear in sectioning
3/4 R
Dimension inside object
1/2 R
Place crossed lines at center of arc
Dimension outside object
1/4 R
Arrow outside object
1/8 R
Small radii are dimensioned as above

Fig. 7-23. Dimensioning radii.

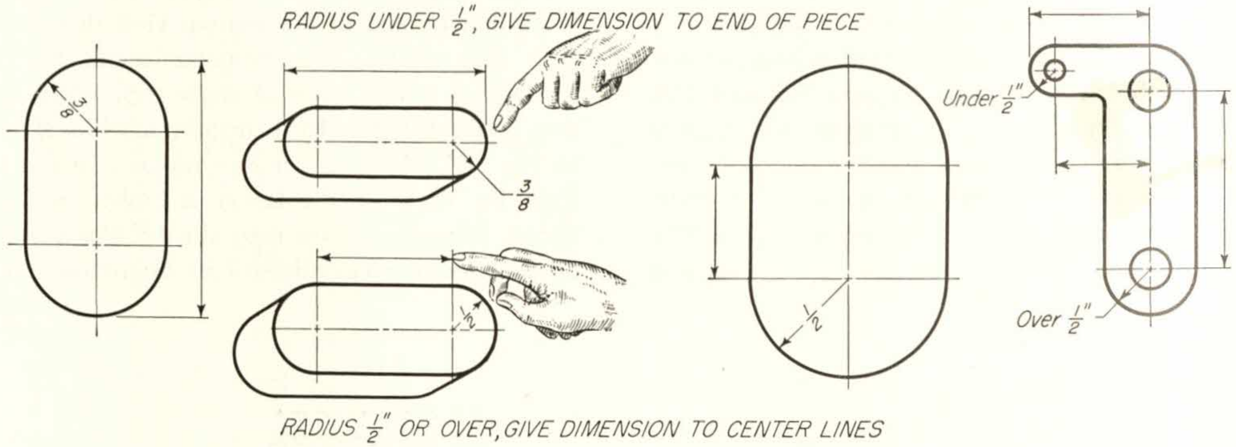

RADIUS UNDER 1/2", GIVE DIMENSION TO END OF PIECE
3/8
3/8
1/2
1/2
Under 1/2"
Over 1/2"
RADIUS 1/2" OR OVER, GIVE DIMENSION TO CENTER LINES

Fig. 7-24. Dimensioning of round-end shapes.

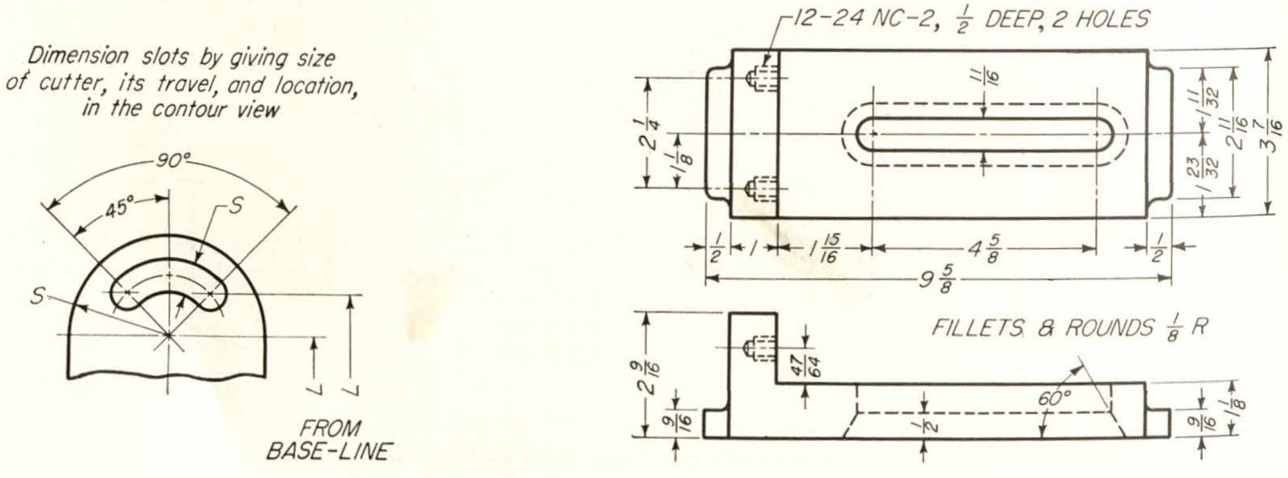


Fig. 7-25. Straight and curved round-end slots.

base line and terminating in points on the curve, which also are dimensioned laterally. These points are actually spaced and dimensioned on a series of rectangular coordinates.

7-20. Angles. The arrowheads of the dimension for an angle are placed on an arc struck from the point of intersection of the sides (see Fig. 7-28). For small angles, the figures are placed to read vertically; for the larger angles, the figures are placed radially. An angle may also be dimensioned by either of the methods shown at the right in Fig. 7-28. When angles are given in degrees and minutes, the two figures are shown closed up without a dash, for example, 45°17′ (see Fig. 7-46 also).

7-21. The chamfer, countersink, and counterbore. Chamfers are dimensioned as shown in Fig. 7-29*A*. A 45° chamfer is dimensioned by giving the angle and its width as a note. If the angle is other than 45°, the angle and the width should not be given as a note but should appear at the point of the chamfer as shown at the lower right in the illustration. Notes for necks and undercuts appear at the top in the illustration.

The left portion of Fig. 7-29*B* shows the manner in which the countersink is drawn and dimen-

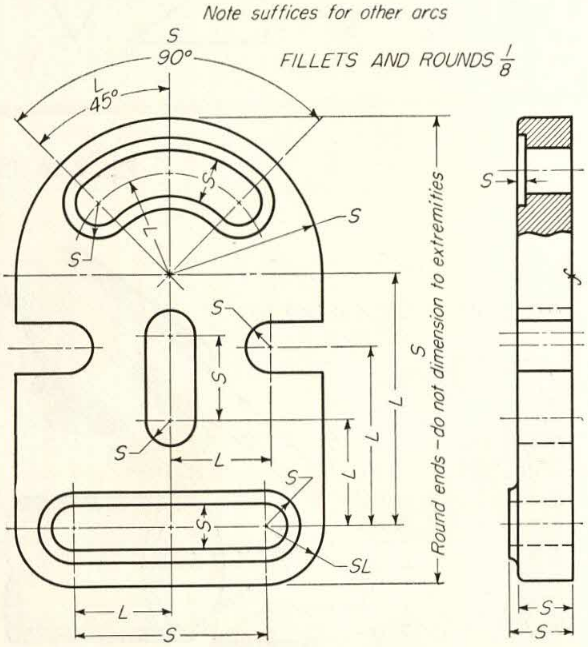

Note suffices for other arcs
S
90°
L
45°
FILLETS AND ROUNDS 1/8
S
S
S
S
S
S
L
S
S
L
L
L
S
SL
Round ends – do not dimension to extremities
L
S
S
S
f

Fig. 7-26. Location and size dimensions for slots.

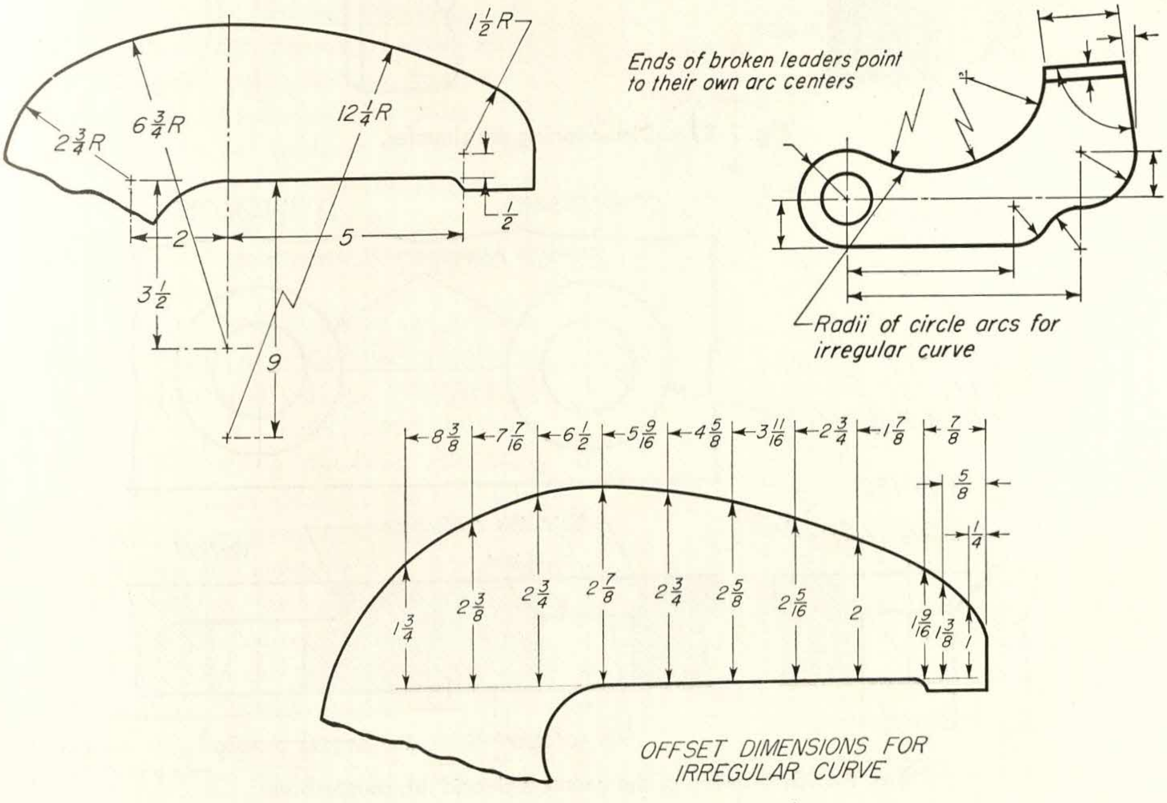

1½R
2¾R
6¾R
12¼R
2
5
½
3½
9
Ends of broken leaders point to their own arc centers
R
Radii of circle arcs for irregular curve
8⅜
7 7/16
6½
5 9/16
4⅝
3 11/16
2¾
1⅞
⅞
⅝
¼
1¾
2⅜
2¾
2⅞
2¾
2⅝
2 5/16
2
1 9/16
1⅜
1
OFFSET DIMENSIONS FOR IRREGULAR CURVE

Fig. 7-27. Dimensioning circular arcs and irregular curves.

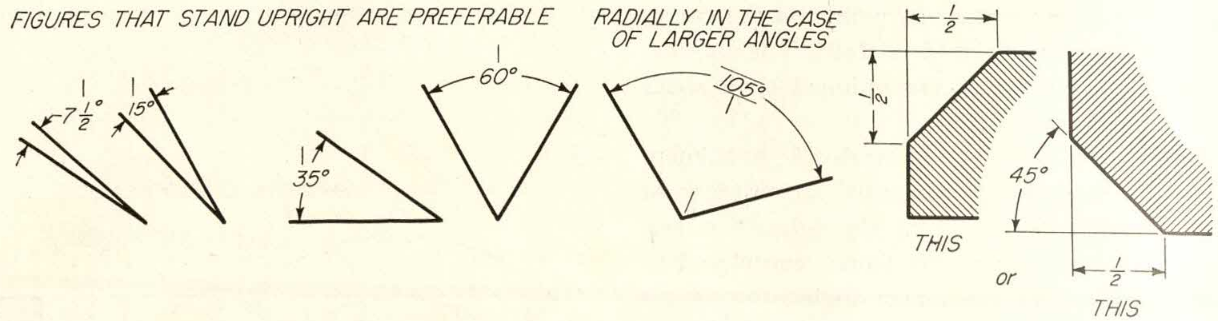

FIGURES THAT STAND UPRIGHT ARE PREFERABLE
7 1/2°
15°
35°
60°
RADIALLY IN THE CASE OF LARGER ANGLES
105°
1/2
1/2
THIS
or
45°
1/2
THIS

Fig. 7-28. Dimensioning angles.

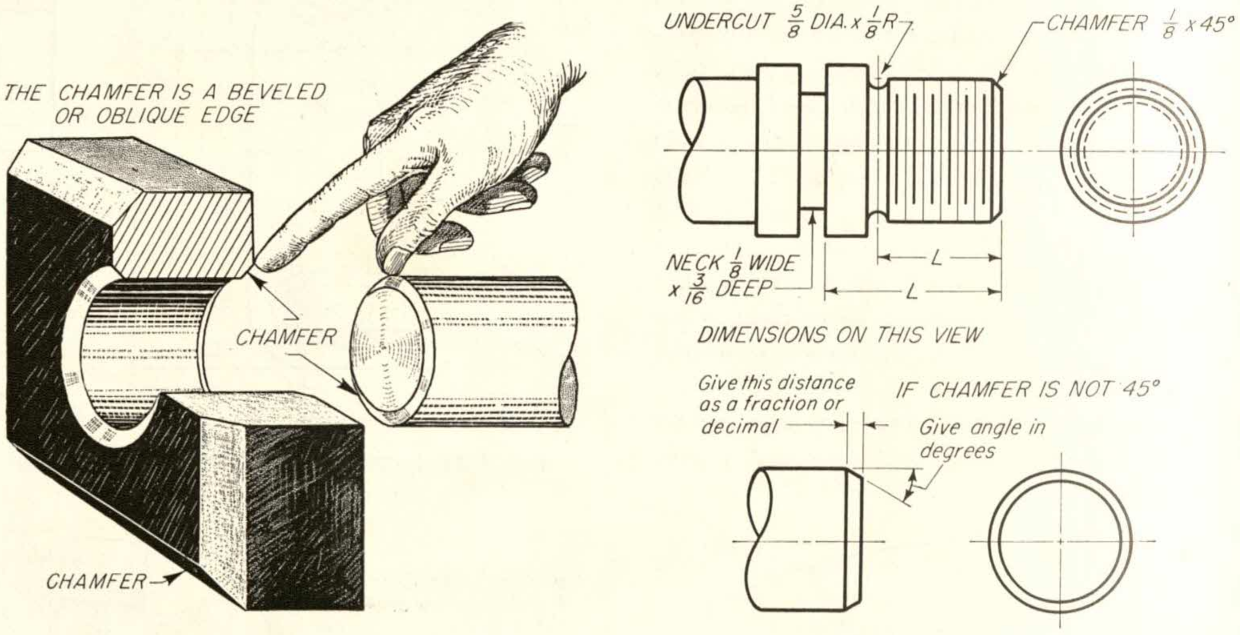

THE CHAMFER IS A BEVELED OR OBLIQUE EDGE
CHAMFER
CHAMFER
CHAMFER
UNDERCUT 5/8 DIA. x 1/8 R
CHAMFER 1/8 x 45°
NECK 1/8 WIDE x 3/16 DEEP
L
L
DIMENSIONS ON THIS VIEW
Give this distance as a fraction or decimal
IF CHAMFER IS NOT 45°
Give angle in degrees

Fig. 7-29A. Dimensioning the chamfer.

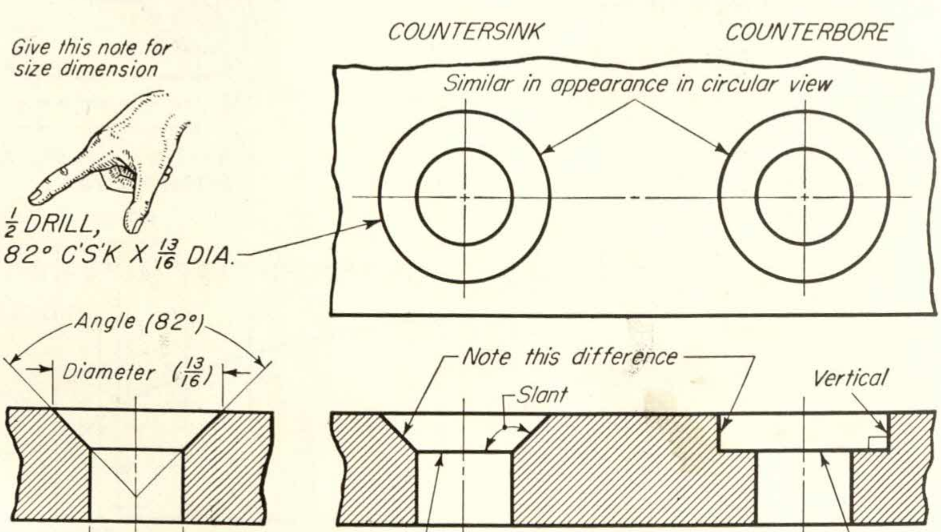

Give this note for size dimension
1/2 DRILL, 82° C'S'K X 13/16 DIA.
COUNTERSINK
COUNTERBORE
Similar in appearance in circular view
Angle (82°)
Diameter (13/16)
Drill (1/2)
Note this difference
Slant
Vertical
Do not overlook this line on your drawing

Fig. 7-29B. Drawing of the countersink and the counterbore.

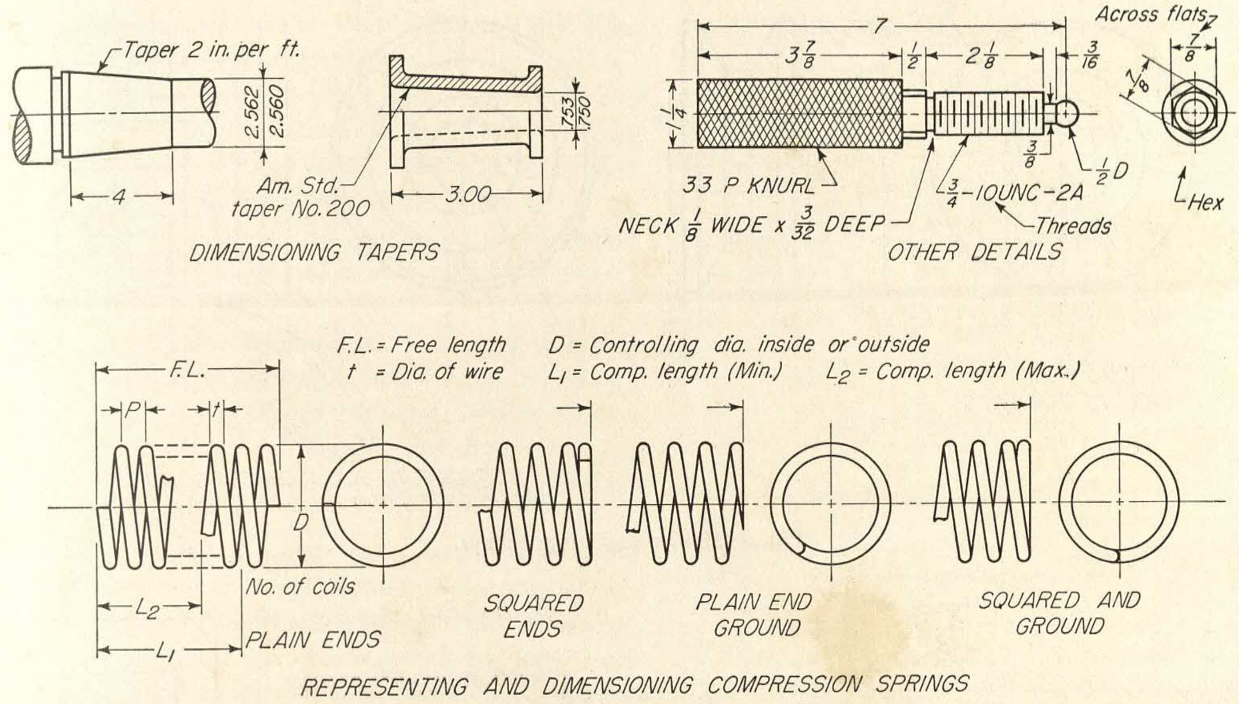


Fig. 7-30. Dimensioning various details. (From ASA Z14.1—1946.)

sioned. The right portion compares it with the drawing of the counterbore. (For dimensioning the counterbore and other holes, see Fig. 7-19.)

7-22. Threads, tapers, springs, bushings, etc. Figure 7-30 illustrates the manner in which screw threads, tapers, compression springs, and other common features are dimensioned by notes. The dimensioning of bushings is shown in Fig. 7-31. Figure 7-32 illustrates the dimensioning of pulleys. The manner in which a spline key is dimensioned is shown in Fig. 7-33. Ribs are dimensioned as shown in Fig. 7-34*a* and *b*.

7-23. Bent shapes. The minimum bend radius a piece of hollow (tubing) or flat sheet metal will tolerate before fracturing is a design consideration dependent on the kind of material and its thickness. Tables for computing the bend allowance (length of the curve of material in the bent portion) are available in engineering handbooks. The required dimensions are shown in Fig. 7-35*a* and *b*. Give the inside radius, the angle in degrees, the dimensions to mold line points, thickness of material, and the formula for the bend allowance.

7-24. Half sections. Although dimensioning a half section (see Sec. 8-12) is occasionally difficult, the proper use of hidden lines in the external por-

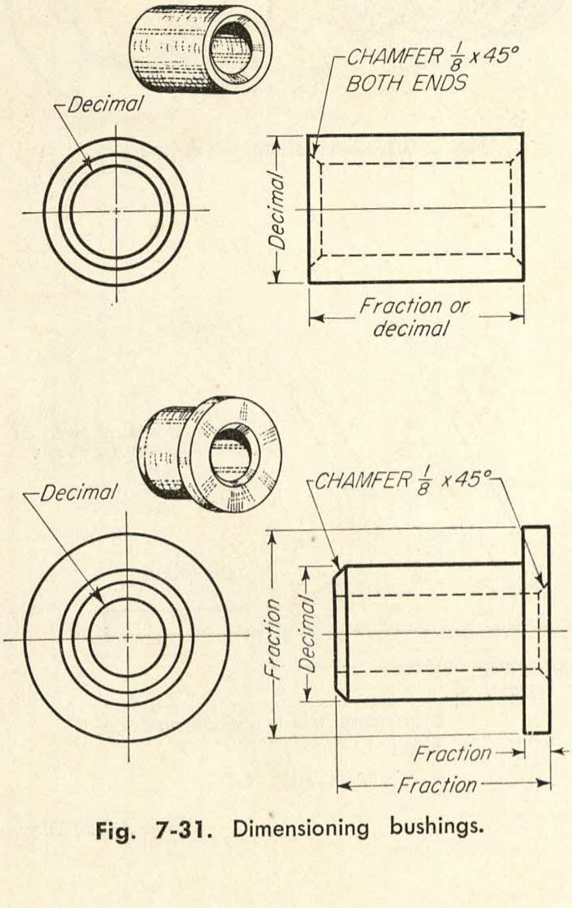
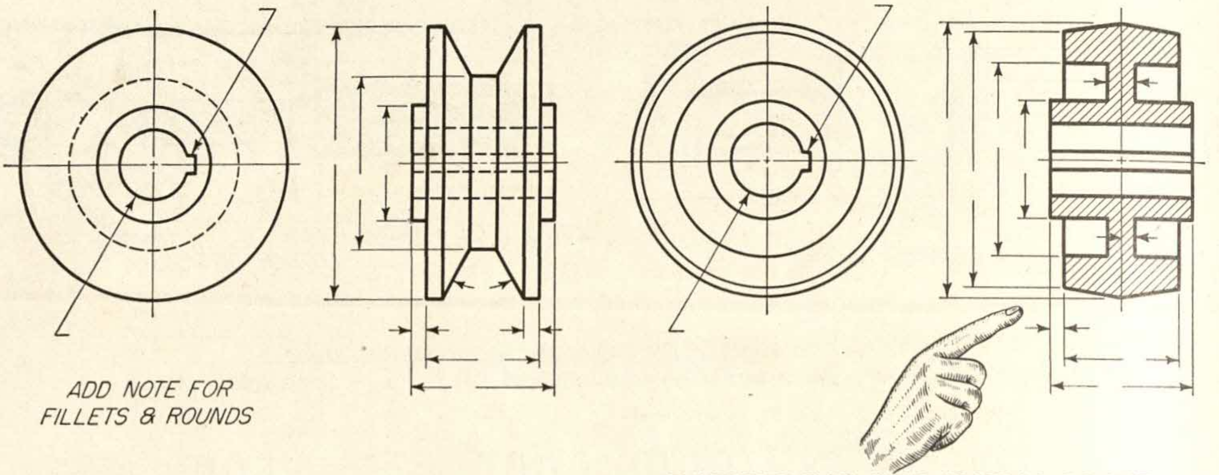


Fig. 7-31. Dimensioning bushings.



ADD NOTE FOR
FILLETS & ROUNDS

IF IMPOSSIBLE TO AVOID CROSSING, DO NOT
BREAK EXTENSION OR DIMENSION LINES

Fig. 7-32. Dimensioning pulleys.

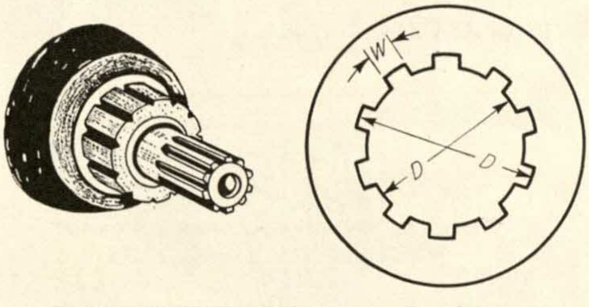
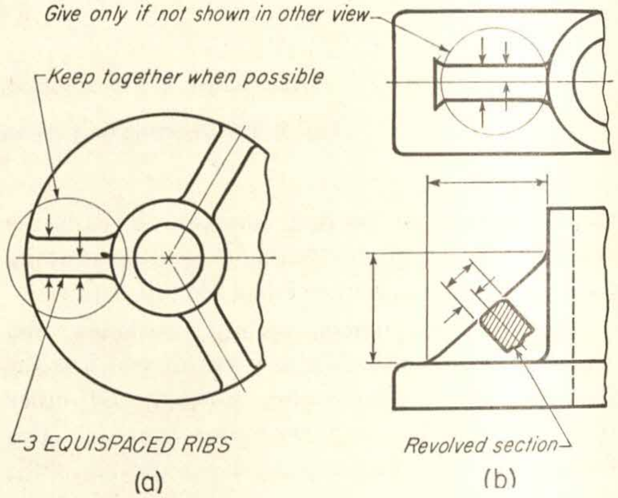


Fig. 7-33. Dimensioning a spline key.



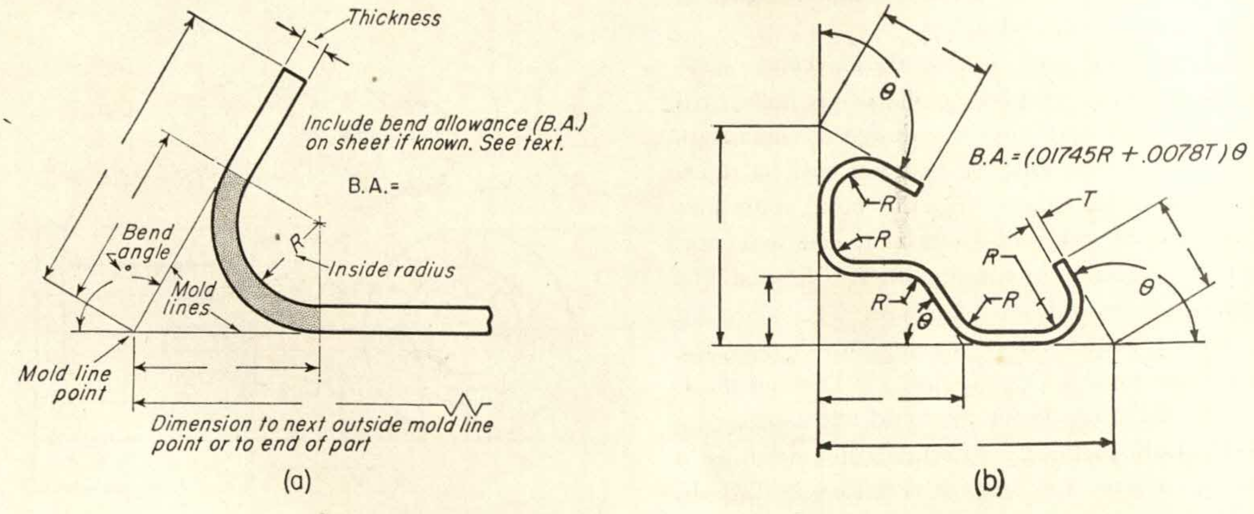
Give only if not shown in other view

Keep together when possible

3 EQUISPACED RIBS

Revolved section

Fig. 7-34. Dimensioning ribs.



Thickness

Include bend allowance (B.A.) on sheet if known. See text.

Dimension to next outside mold line point or to end of part

B.A. = (.01745R + .0078T)θ

Fig. 7-35. Dimensioning for bent shapes.

tion of the half-section view will generally allow the draftsman to dimension such views satisfactorily. In half-section views, it is permissible, and even advisable, to dimension to hidden lines (see Fig. 7-36) in order to avoid confusion and possible misinterpretations. Dimensioning such views requires great care in the placement of dimension and extension lines and usually calls for extensive notes.

7-25. Tabular dimensions. Objects having similar features and functions but varying in size can be represented as a single drawing. Letters are substituted for the dimensioning, and their numerical values are given in tabular form as shown in Fig. 7-37.

7-26. Standard parts. Bolts, screws, keys, pins, wire, rolled shapes, nails, pipes, chains, ropes, etc., are usually standardized features. They are shown symbolically on the drawing and are listed and specified in the bill of materials of an assembly drawing as standard parts. Their actual dimensions, if required, are available in pamphlets published by the ASA or in manufacturers' manuals and engineering handbooks, where they usually appear in tabular dimensioning (see chapter on fasteners and Appendix).

7-27. Base-line dimensioning. To avoid the accumulation of errors that is likely to occur with the use of continuous dimensions (see Fig. 7-8), base-line dimensioning is used for precision work. Base-line dimensioning means that wherever possible all dimensions are referred to a common reference line. A center line or a finished surface is generally used as the reference point for each independent dimension (see Fig. 7-38*A* and *B*). Note in the illustrations that the last dimension is superfluous and may be omitted, since the over-all dimension gives the distance from end to end for the piece. The dimension omitted should always be the least necessary. If desired for checking or reference, the extra dimension may be included and marked with the abbreviation "Ref." Note in Fig. 7-38*B* that dimensioning within a view is always permissible if doing so helps to clarify the presentation.

7-28. Importance and preference in dimensions. Dimensioning practice should always be considered in the light of the manufacturing processes required in making a part, and wherever possible

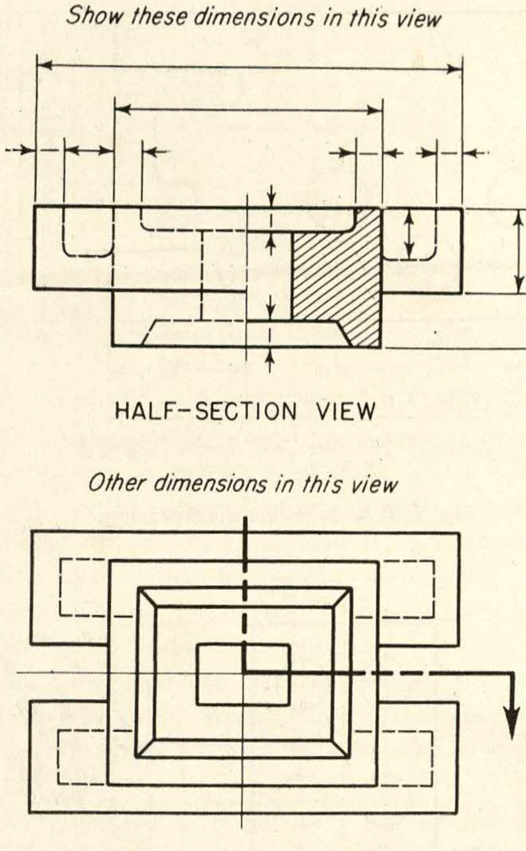
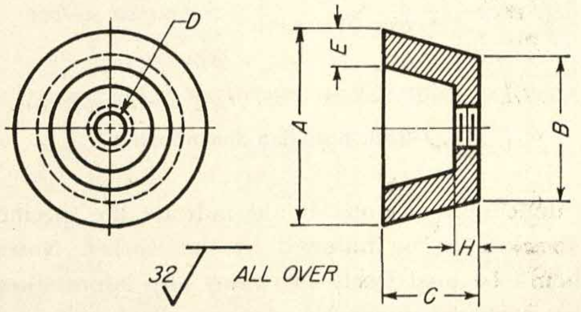
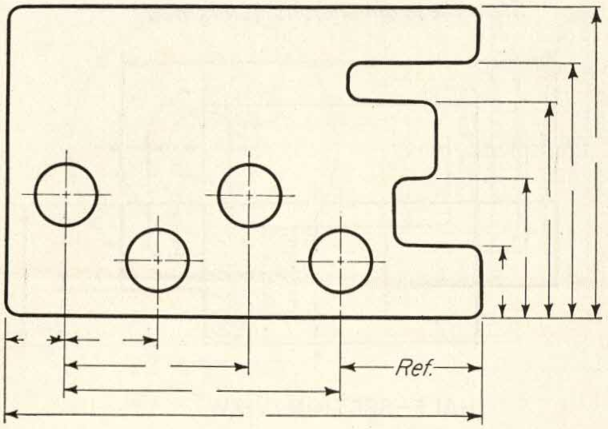

Show these dimensions in this view
HALF-SECTION VIEW
Other dimensions in this view
ORDINARY VIEW

Fig. 7-36. Dimensioning half sections.



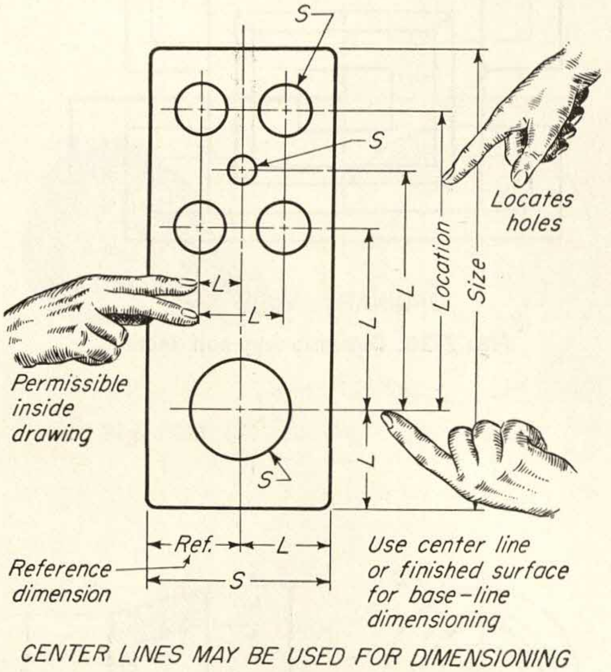
A	*B*	*C*	*D-UNF THD*	*E*	*H*
4	3	2	$\frac{1}{4}-28$	$\frac{1}{2}$	$\frac{1}{2}$
5	$3\frac{3}{4}$	2	$\frac{5}{16}-24$	1	$\frac{3}{4}$
6	$4\frac{3}{4}$	2	$\frac{3}{8}-24$	$1\frac{1}{4}$	1
7	5	2	$\frac{7}{16}-20$	$1\frac{1}{2}$	$1\frac{1}{8}$

Fig. 7-37. Tabular dimensions.



STAGGERING THE DIMENSION FIGURES IS MORE PLEASING

Fig. 7-38*A*. Base-line dimensioning.


S
S
Locates holes
Location
Size
L
L
L
L
L
Permissible inside drawing
S
Ref.
L
Reference dimension
S
Use center line or finished surface for base-line dimensioning

CENTER LINES MAY BE USED FOR DIMENSIONING

Fig. 7-38*B*. Base-line dimensioning.

a dimension or note should indicate the specific procedure to be followed by the worker. Notes should be used freely to convey any information that a figured dimension alone cannot supply.

The draftsman can help the worker in the shop to produce accurately the part shown in the drawing by following a recognized sequence of importance and preference when specifying dimensions.

For the highest degree of accuracy, the sequence of importance in giving size dimensions is as follows:

1. Finished surface to finished surface
2. Finished surface to unfinished surface
3. Unfinished surface to unfinished surface

For location dimensions, the preferred sequence is:

1. Center line to center line
2. Center line to finished surface
3. Finished surface to finished surface
4. Center line to unfinished surface
5. Finished surface to unfinished surface
6. Unfinished surface to unfinished surface

When dimensioning drawings for the shop, the draftsman should take particular care to be certain that the dimensions are direct and do not require calculations on the part of the worker.

7-29. Changes and corrections of dimensions. When it is necessary to alter or correct a dimension and the change is not sufficiently important to warrant remaking the entire drawing, the dimension figure may be altered by one of the methods shown in Fig. 7-39 and a note with the date of the change added in the title block (or just above it, if no space is allotted for this in the block). Of course, if the change radically alters the appearance and design of the part, a new drawing must be prepared.

7-30. Final check. A suitable application of the dimensioning principles discussed in this chapter will enable the draftsman to dimension any object adequately. As a final step, the drawing should be checked to make sure that all over-all, size, and location dimensions have been given and that the dimensions shown are those necessary for the manufacture of the part and not those used to make the drawing. The drawing should also be checked to be certain that dimensions have been placed on the view showing the true size or shape of a particular feature and that no line of the object or center line has been used as a dimension line. Although unnecessary dimensions should be avoided, the dimensions given must be sufficient for the manufacture, assembly, and inspection of the part. The scale, material, number of pieces required, and all other pertinent information listed in the bill of materials, the title block, and the record strip must be checked to be sure that sufficient data have been supplied to allow the workman in the shop to do his job accurately and efficiently.

7-31. Interchangeable manufacture and selective assembly. In industrial practice, it has proved feasible to manufacture each of several mating parts in plants remote from each other and still assure suitable functioning when the pieces are brought together in assembly. This has been made possible by setting up standards that specify allowable variations in size for mating parts under various specific conditions. This permitted variation in size is known as "tolerance." It is the function of the designer to specify the desired tolerances on mating parts, which the draftsman then expresses as dimensions on the drawing. The draftsman can make his own computations for these dimensions from standard tables if he knows the required mating conditions, or "fit," which are discussed in Sec. 7-33. The tolerance of mating parts is given on a drawing by specifying the maximum and minimum size limits of each of the mating members. This phase of dimensioning practice is known as *limit dimensioning* and is of vital importance in the quantity manufacture of parts for interchangeable and selective assembly.

7-32. Definition of terms. The terms used in limit dimensioning of cylindrical parts and their definitions are as follows:

Nominal size. The (fraction or decimal) dimension used for the purpose of general identification of the diameter. See column heading, Nominal Size Range, in Table 26 in the Appendix.

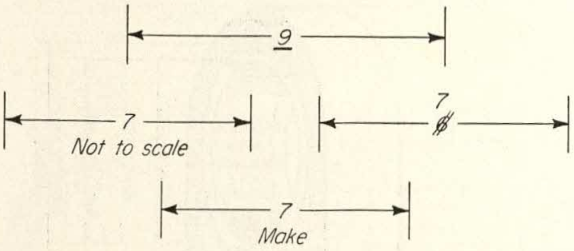
Basic size. The exact (decimal) size to which the allowances and tolerances are applied to obtain the limits. See Sec. 7-35.

Limits. The maximum and minimum permissible sizes of a part. See Sec. 7-36.

Tolerance. The total permissible variation in the size of a part. The difference between the limits of size. See Sec. 7-37.

Allowance. The minimum acceptable clearance (for clearance fits) or the maximum acceptable interference (for interference fits) between two mating members. It is the decimal dimension that indicates the loosest or the tightest fit between parts. For clearance fits, the allowance is positive; for interference fits, it is negative. See Sec. 7-38.

7-33. Classes of fits. Fit is the general term used to signify the *range of tightness* between mating parts after the proper tolerances and allowances have been applied to the mating members.



WHEN CHANGE IN DIMENSION IS MADE NOTE IT IN TITLE BLOCK OR RECORD STRIP

Fig. 7-39. Changes and corrections in dimensions.

Fits are of three general types: the clearance fit, the interference fit, and the transition fit (see Fig. 7-40).

In the *clearance fit,* the internal member is smaller than the external member, and the mating parts move rather freely. The space between the parts allowing this freedom is termed the "allowance" and is indicated as positive.

In the *interference fit,* there is always an interference of metal because the internal member is larger than the external member, and the allowance is negative.

A *transition fit* is one in which the parts are made to allow either a clearance or interference fit—a maximum external member and a minimum internal member will give a clearance fit; a minimum external member and a maximum internal member will give an interference fit. The transition fit requires *selective assembly* for the mating parts, whereas with clearance or interference fits *inter-*

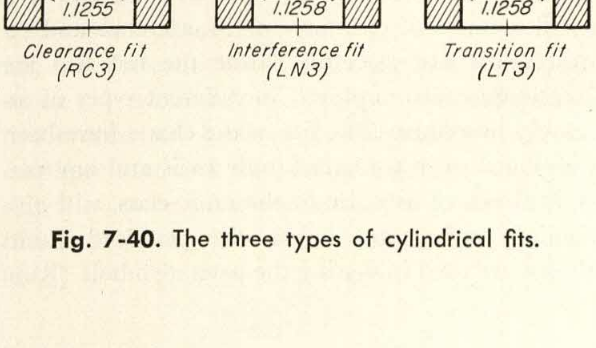
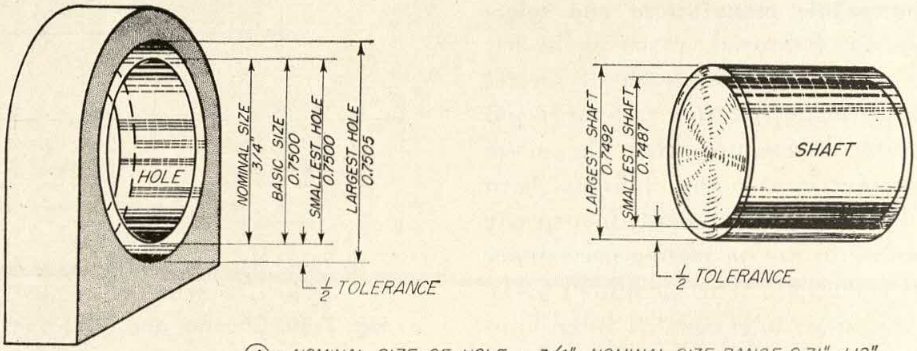


Fig. 7-40. The three types of cylindrical fits.



Ⓐ - NOMINAL SIZE OF HOLE = 3/4", NOMINAL SIZE RANGE 0.71"-1.19"

Ⓑ - LIMITS

See table 26 in appendix

HOLE		SHAFT	
+ 0.0005	0.0000	-0.0008	-0.0013

Ⓒ - BASIC SIZE
0.7500

SMALLEST HOLE 0.7500
− LARGEST SHAFT 0.7492
MIN. ALLOWANCE 0.0008

TOLERANCE ON HOLE 0.0005

TOLERANCE ON SHAFT 0.0005

Ⓓ -

$$\frac{\text{SMALLEST HOLE}}{\text{LARGEST HOLE}} = \frac{0.7500 + 0.0000}{0.7500 + 0.0005} = \frac{0.7500 \text{ LIMIT}}{0.7505 \text{ LIMIT}}$$

Ⓔ -

$$\frac{\text{LARGEST SHAFT}}{\text{SMALLEST SHAFT}} = \frac{0.7500 - 0.0008}{0.7500 - 0.0013} = \frac{0.7492 \text{ LIMIT}}{0.7487 \text{ LIMIT}}$$

COMPUTATIONS: BASIC HOLE SYSTEM, RUNNING AND SLIDING FITS, CLASS RC3

Fig. 7-41. Computing limit dimensions.

changeable assembly may be used. With transition fits, however, the parts are graded in size, and it is often possible to obtain a closer fit.

7-34. ASA cylindrical fits. The ASA, ABC (American-British-Canadian) standard types and classes of fits (see Table 26 in Appendix) are as follows:

Running and sliding fits—Classes RC 1 through RC 9

Clearance locational fits—Classes LC 1 through LC 11

Transition locational fits—Classes LT 1 through LT 7

Interference locational fits—Classes LN 2 and LN 3

Force and shrink fits—Classes FN 1 through FN 5

The first two are free fits, the third allows a small amount of clearance or interference and requires selective assembly, while the last two are interference fits employed in different types of assembly procedure. The fits in the charts have been developed on a unilateral hole basis and any prescribed fits, of any size in the same class, will give similar performance when the standard limits shown are used in mating the parts. Symbols (Running and sliding fits—Class RC 1, etc.) should not appear on the drawing sheet. Only the limit sizes for the dimensions are required.

7-35. Computations of limit dimensions. The correct fit between engaging surfaces of mating parts may be found by using either the *basic-hole system* in which the *allowance* is applied to the shaft, or the *basic-shaft system* where the *allowance* is applied to the hole. In the basic-hole system, the design size of the hole is taken as the basic dimension, and the size of the shaft is determined by the limit dimensions of the hole and the type of fit desired. The nominal size of the hole (if a fraction) is converted to the basic size (decimal dimension), and the limit dimensions for both hole and shaft are derived by adding or subtracting, whichever the case may be, the limit figures taken directly from the proper fit chart. When the basic-shaft system is used, the design size (or the maximum dimension if tolerances have already been applied) of the shaft is taken as the basic size, and by applying (adding for a clearance fit or subtracting for an interference fit) the permissible allowance to this basic- (design or maximum) shaft size, the basic size of the hole is found. This dimension is then used as the basic size to compute the limits for both shaft and hole according to the basic-hole system. The basic-shaft system should be employed only when standard-size (or required-size) shafting must be used. Its use is always indicated by adding the letter S to the symbol, for instance, RC 3S.

7-36. Limit dimensions, basic-hole system. To show how Table 26 in the Appendix is applied, let us find the limits for the hole and shaft shown in Fig. 7-41. The nominal size of each of the parts is $\frac{3}{4}$ in. and the basic size is 0.7500. They are to work as a Class RC 3 running and sliding fit which permits interchangeable assembly. Referring to the left-hand column in the table under that heading we find the nominal size range given by the figures 0.71–1.19. Reading from these figures across horizontally to the column heading Class RC 3, we find that the size of the hole may vary from the basic size 0.7500 by +0.0005 and 0.0000. The shaft varies from the basic size by −0.0008 and −0.0013. These limits are added to or subtracted from the basic size dimension 0.7500 to give the absolute limits in size for the largest and smallest hole and the largest and smallest shaft. The allowance is determined by subtracting the dimension for the largest shaft from the figures for the smallest hole. In this case it is 0.0008. When assembled, no matter where the size dimensions for each part may range between their limits, the mating surfaces will perform satisfactorily the task for which they are intended.

7-37. Ways of indicating tolerance. Tolerances are indicated on a drawing either by a general note or by specific limits on the parts affected. A general note indicating tolerance, such as "All fractional dimensions to $\pm\frac{1}{32}$ in.," is assumed to apply to all features on which the tolerance has not been specifically indicated. In the absence of specific tolerances or a general note, the worker in the shop will, in general, assume a tolerance of $\pm\frac{1}{64}$ in. for fractional dimensions and ±0.01 for a two-place decimal dimension, ±0.001 for a three-place decimal, etc.

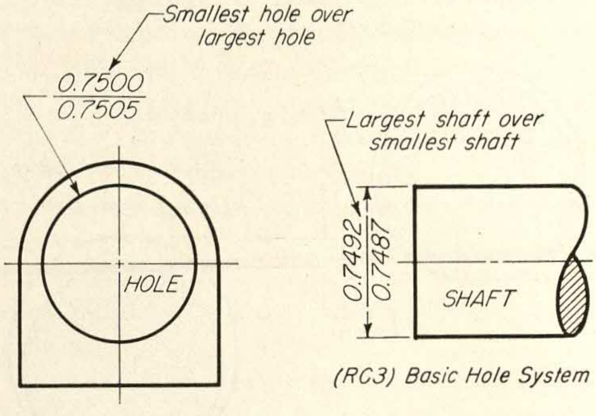

Smallest hole over largest hole
0.7500
0.7505
HOLE
Largest shaft over smallest shaft
0.7492
0.7487
SHAFT
(RC3) Basic Hole System

Fig. 7-42. Placing limits in the dimensions.

Specific tolerances may be either *unilateral* or *bilateral*. A unilateral tolerance is one in which the variation from the basic size is in one direction (plus or minus), but not both. Unilateral tolerances are preferably indicated as shown in Fig. 7-42, with the two limits given one above the other, but they may also be expressed by giving one limit size and the tolerance, for example, 0.7500 + 0.0005 or $0.7500\,{}^{+0.0005}_{-0.0000}$. Bilateral tolerances are used when the variation from the basic size may be either plus or minus, for example, 0.100 ± 0.002 or $0.100\,{}^{+0.002}_{-0.002}$. As a general rule, nonmating members are toleranced bilaterally, while mating surfaces are toleranced unilaterally.

In specifying tolerances, the draftsman should keep in mind the method that will be used to remove excess material in the machining operation and should place the dimension limits accordingly. In the case of a hole, for example, the machinist will reach the smallest size first, and so the small dimension is placed over the dimension for the largest hole. A shaft, on the other hand, is turned down from the larger to the smaller dimension; thus, the larger limit is placed over the smaller limit (see Fig. 7-42).

7-38. Allowances. Although technically the term *allowance* means the minimum clearance between mating parts, in shop practice it is common to speak of minimum and maximum allowance. The minimum allowance between two pieces in assembly is the difference between the smallest hole and the largest shaft (see Fig. 7-43). For clearance fits, it represents the tightest permissible fit between the two parts in assembly; for interference fits, it is the maximum permissible interference between the two members. The maximum allowance is the difference between the largest hole and the smallest shaft and represents the loosest permissible fit (or minimum interference in the case of interference fits) between the two parts in assembly.

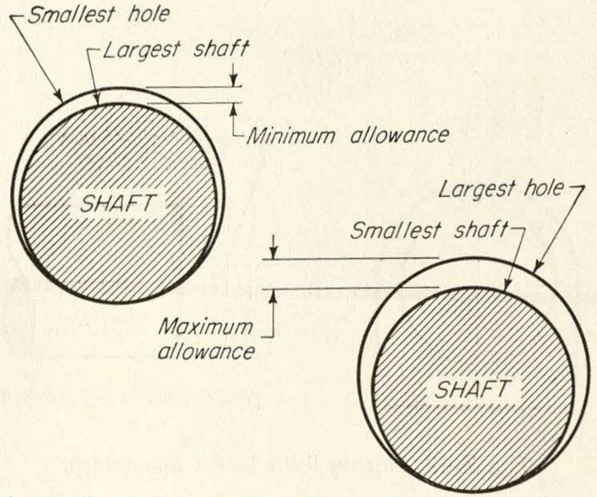


Fig. 7-43. Minimum and maximum allowance for clearance fit.

7-39. Cumulative tolerances. The shaft shown in Fig. 7-44 has been dimensioned to function with various types of bearings and bearing surfaces. The tolerances on the various diameters have been computed and specified according to the desired fits with the mating forms. Superfluous dimensions should be avoided, and errors in cumulative tolerances held down to an absolute minimum by using base-line dimensioning whenever possible. Continuous dimensions always tend to build up inaccuracies in tolerances. Note in the illustration that a critical surface at about the center of the shaft has been used as the base line from which the length dimensions are given, thus nullifying the possibility of cumulative errors.

7-40. Dimensioning keyways and key seats. For the closer tolerances required in some phases of interchangeable assembly, decimal limits are used in dimensioning keyways and key seats, as shown in the right portion of Fig. 7-45. The ordinary method of specifying these features is seen at the left.

7-41. Tolerance of angles. In locating points angularly, the likelihood of errors occurring increases with their distance from the vertex. If their location is of a critical nature, the points should be located by rectangular coordinates. However, where angular dimensioning is acceptable, the

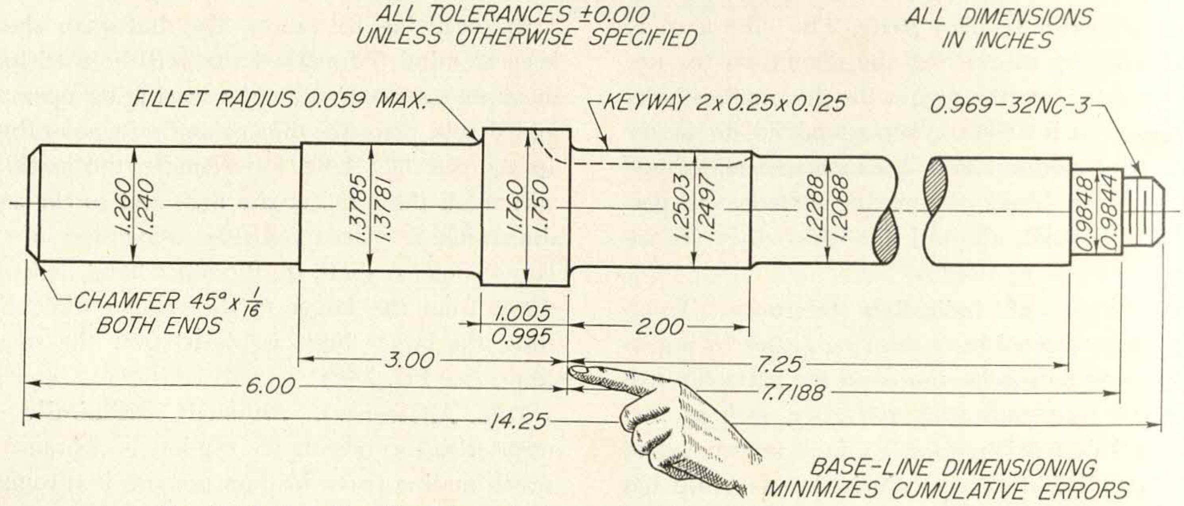
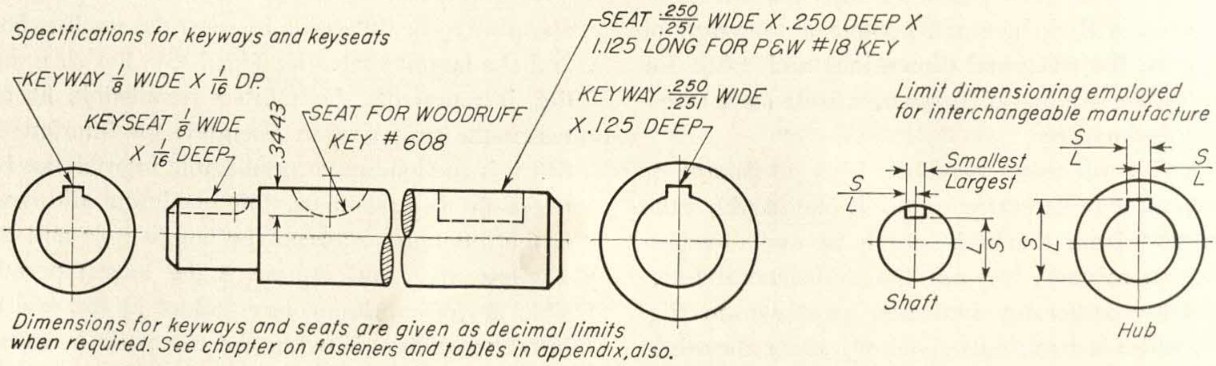


Fig. 7-44. Base-line limit dimensioning to avoid cumulative errors in tolerance.


Specifications for keyways and keyseats
KEYWAY 1/8 WIDE X 1/16 DP.
KEYSEAT 1/8 WIDE
X 1/16 DEEP
.3443
SEAT FOR WOODRUFF
KEY #608
SEAT .250/.251 WIDE X .250 DEEP X
1.125 LONG FOR P&W #18 KEY
KEYWAY .250/.251 WIDE
X.125 DEEP
Limit dimensioning employed
for interchangeable manufacture
S
L
Smallest
Largest
S
L
S
L
S
L
L
S
Shaft
Hub

Dimensions for keyways and seats are given as decimal limits when required. See chapter on fasteners and tables in appendix, also.

Fig. 7-45. Dimensioning for keyways and key seats.

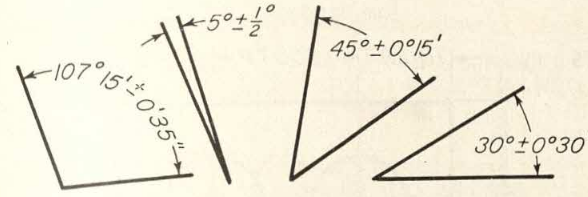


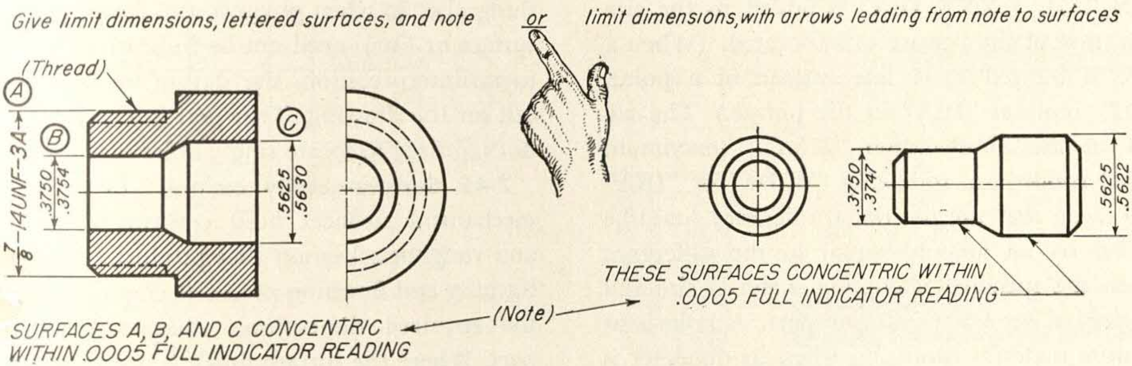
Fig. 7-46. Tolerances on angles.

tolerance is given bilaterally (Fig. 7-46). Angles for which no limits have been specified are assumed to have a tolerance of ±½°.

7-42. Tolerance of concentricity. Since a very slight decimal variance in concentricity of cylindrical forms cannot be adequately represented (their respective center lines would appear coincidental on the drawing sheet), concentric tolerances for cylindrical surfaces must be given by note. Two different methods are shown in Fig. 7-47.

7-43. Tolerances of form. In addition to concentricity and roundness, tolerances of form (see Fig. 7-48) can refer to (*a*) straightness; (*b*) and (*c*) parallelism; (*d*) angular displacement; (*e*), (*f*), and (*g*) squareness; (*h*) flatness; and (*k*) symmetry. The dimensions with the notes are used to signify the actual tolerance variation permitted from the perfect geometry implied by the drawing on the sheet. Where applicable, the datum (reference line or surface) must always be noted on the drawing.

7-44. Positional tolerances. The actual positions of holes and other features may be shown by giving individual tolerances in the coordinate dimensions that locate them, as seen at the left in Fig. 7-49. A more precise method appears at the right, where the "true-position" expression consists of two parts: (1) The abbreviation "TP" is added


Give limit dimensions, lettered surfaces, and note or limit dimensions, with arrows leading from note to surfaces

(Thread)
A
B
C
7/8-14UNF-3A
.3750
.3754
.5625
.5630
(Note)
SURFACES A, B, AND C CONCENTRIC WITHIN .0005 FULL INDICATOR READING
.3750
.3747
.5625
.5622
THESE SURFACES CONCENTRIC WITHIN .0005 FULL INDICATOR READING

Fig. 7-47. Dimensioning for concentricity of cylindrical forms.

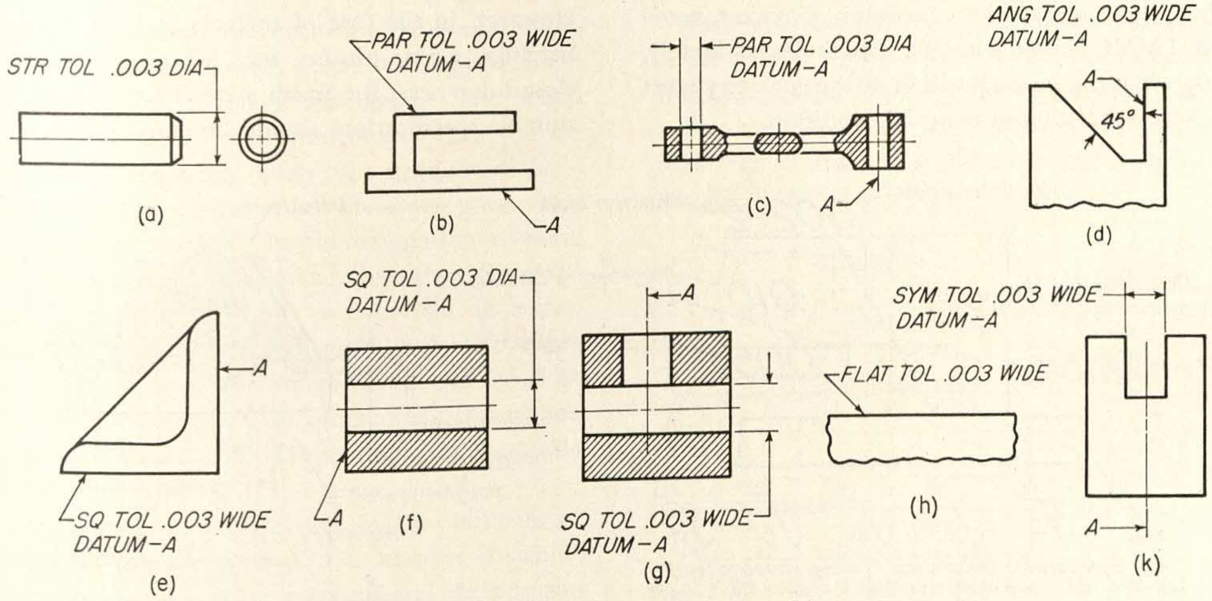


Fig. 7-48. Dimensioning for tolerances of form.

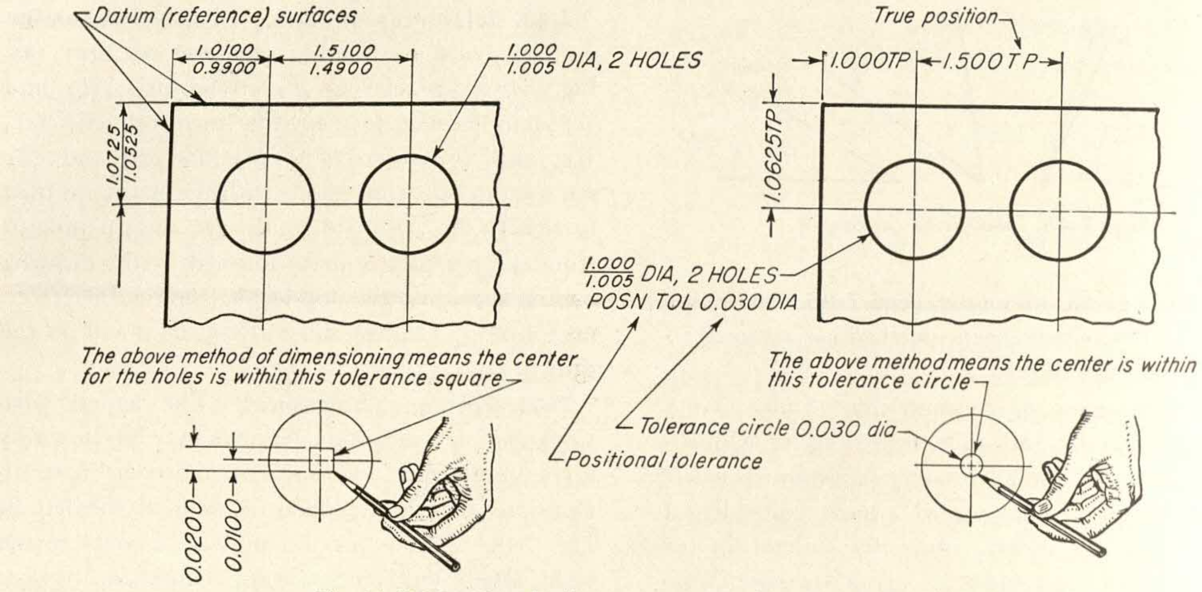

Datum (reference) surfaces
1.0100
0.9900
1.5100
1.4900
1.000
1.005 DIA, 2 HOLES
1.0725
1.0525
The above method of dimensioning means the center for the holes is within this tolerance square
0.0200
0.0100
True position
1.000TP
1.500 TP
1.0625TP
1.000
1.005 DIA, 2 HOLES
POSN TOL 0.030 DIA
The above method means the center is within this tolerance circle
Tolerance circle 0.030 dia
Positional tolerance

Fig. 7-49. Positional tolerances; precise location of holes.

to the coordinate dimensions, and (2) the phrase "POSN TOL X.XXX DIA" is added to the size specification of the feature to be located. (When a feature is located by a line instead of a point, "WIDE" replaces "DIA" in the phrase.) The addition of the abbreviation "MMC" (maximum material condition) following "WIDE" or "DIA" would mean that the positional tolerance could be exceeded by an amount equal to the difference between the specified maximum material size and the actual size on a particular part. A hole is at maximum material condition when its diameter is at the minimum size specified. On the other hand, pins, shafts, bolts, etc., are at maximum material when they are at the maximum diameter specified. "MMC" should not be used indiscriminately, only when the stated position or the geometry must be kept at maximum material condition.

True position is true only in reference to something else; so when obvious, the datum (reference surface or line) need not be indicated, but if open to misinterpretation, the datum must be pointed out on the drawing. True-position expressions are not required to locate single holes or features.

7-45. Surface-quality control. In general, few mechanical surfaces need control of smoothness and roughness beyond that produced by the usual forming and finishing processes employed to obtain the required dimensional characteristics of the part. Where the surface finish is not too important (nonmating and nonworking surfaces) the use of the surface-quality-control symbol is discouraged. However, in the case of surfaces such as those on bearings, gears, pistons, etc., which may require close tolerances, the finish symbol designating the suitable specifications should be employed.

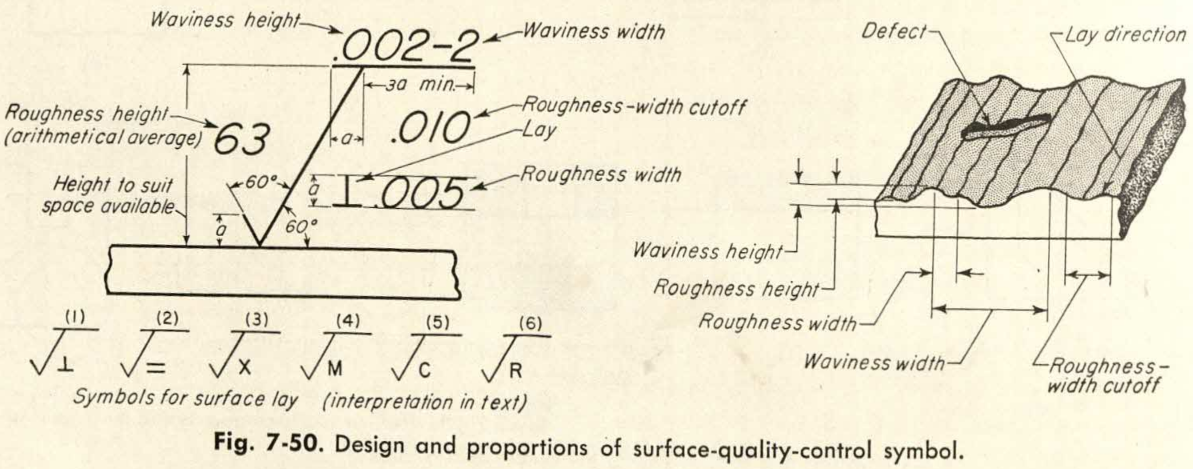


Fig. 7-50. Design and proportions of surface-quality-control symbol.

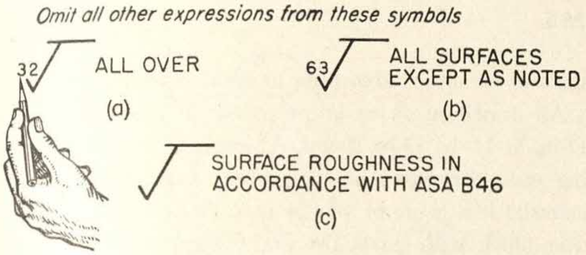


Fig. 7-51. Surface-roughness symbols, for use only as a general note.

The design and proportions of the complete surface-quality-control symbol are at left in Fig. 7-50. It is always drawn upright, with its longer arm to the right, capped by a horizontal extending farther to the right than the left. The pictorial (right) illustrates the meaning of the expressions in the symbol. *Waviness* refers to the prominent or larger irregularities of the surface. The height or width of waviness is given in the symbol as the maximum numerical value (in decimal inches). *Surface roughness* refers to the small peaks and valleys. The roughness-height-designating numeral is given as the arithmetical deviation from the mean line (surface) and is expressed in microinches [one microinch = one-millionth (0.000001) inch]. When only the roughness height need be specified for an object, all other numerical expressions are omitted from the symbol (see Fig. 7-51*a* and *b* and Fig. 7-37).

Lay refers to the direction of the scratches or tool marks on the surface. The manner in which it lies in relation to the material and the position of the expression in the symbol are shown at the bottom left of Fig. 7-50: (1) perpendicular, (2) parallel, (3) angular, (4) multidirectional, (5) circular, and (6) radial. In denoting the *width cutoff* value, 0.030 is the preferred standard for most surfaces.

A single symbol for the control of surface roughness for a single part or a group in assembly can be incorporated in a drawing as a general note. Three of these symbols are shown in Fig. 7-51*a* to *c*. One application (*a*) may be seen in Fig. 7-37. Other methods of application for the surface-quality-control symbol are shown in Fig. 7-52. When used locally, the apex of the symbol touches a line of a surface, a leader line, a center line, or a witness (extension) line.

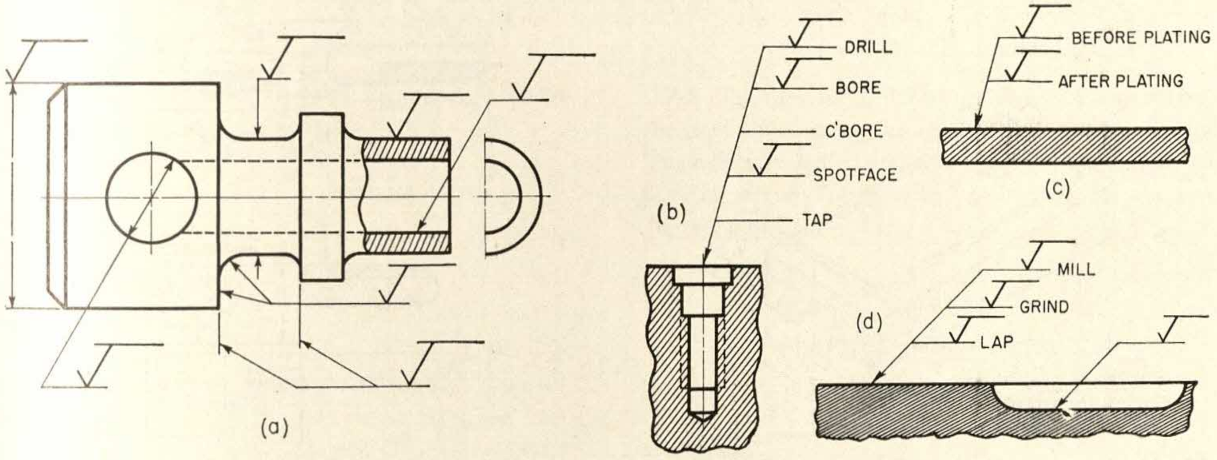


Fig. 7-52. Local applications of the surface-quality-control symbol.

Since a surface-quality-control symbol refers only to the kind of finish desired on a surface and limit dimensions indicate the maximum and minimum acceptable dimensions of a feature, both are employed in a drawing when their use is required (see Fig. 7-53).

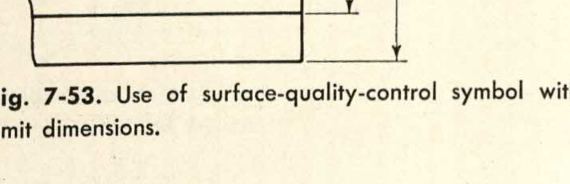


Fig. 7-53. Use of surface-quality-control symbol with limit dimensions.

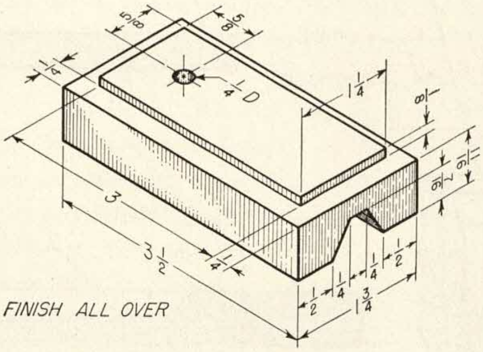
PROBLEMS

Although these problems have been selected primarily to provide practice in applying correct dimensioning procedures, they also afford training in the selection of views, in the choice of a suitable scale for the object, and in the spacing of the views so as to permit the placement of dimensions and notes without crowding.

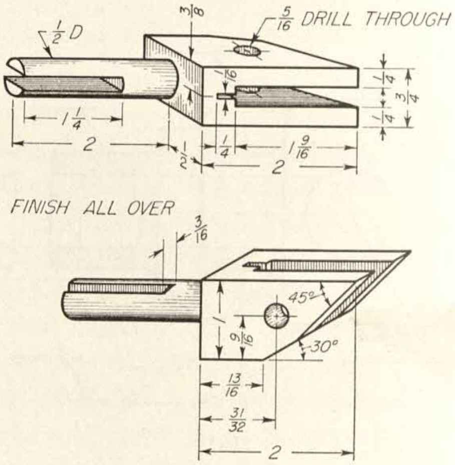
A preliminary thumbnail sketch (to be submitted to the instructor) will aid in visualizing and solving these problems. When working from the pictorial illustrations, keep in mind that the dimensions given are intended only to make it possible to prepare the necessary orthographics and are not necessarily the ones to be placed on the drawing sheet. Also, it should be pointed out that pictorials of machine forms do not always permit dimensions to be shown according to good practice.

All drawings are to be prepared on standard 8½- by 11-in. or 11- by 17-in. sheets. A simple title form containing only the name of the object, the scale, and the material it is made of may be used instead of a complete title block with parts list and record strip (unless a printed form appears on your sheet).

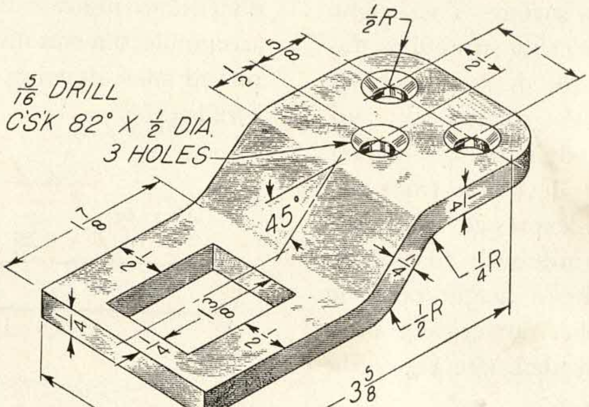
Other dimensioning problems may be selected from the large number of details that make up the assemblies shown in the Problems in Chap. 13. Until the student has read the discussions in Chaps. 9, 10, 12, however, care should be taken to avoid assigning problems which contain details on fasteners, such as screw threads, or require auxiliary views for complete description.



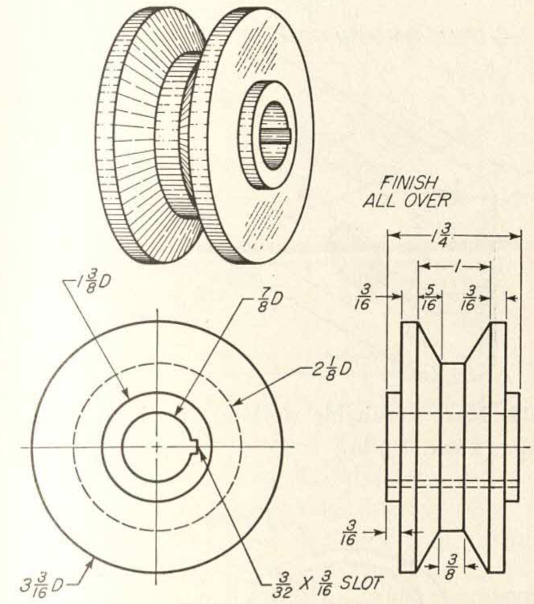
7-1. Make a suitable shop drawing of the cast-iron base. (Time. 2½ hr.)



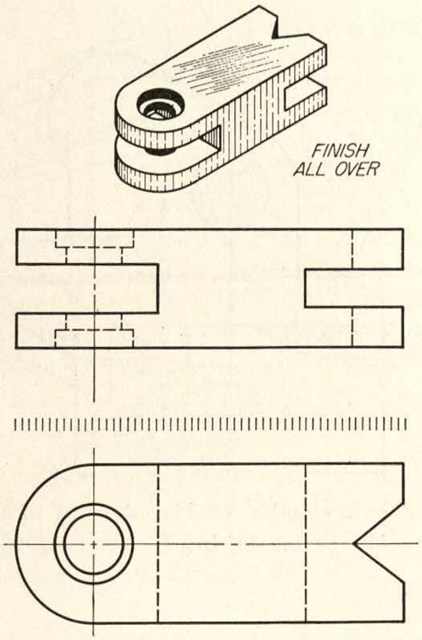
7-2. Make a suitable shop drawing of the brass swivel frame. Show all dimensions in decimals, with the exception of the drilled hole and, of course, the angles. (Time. 3 hr.)



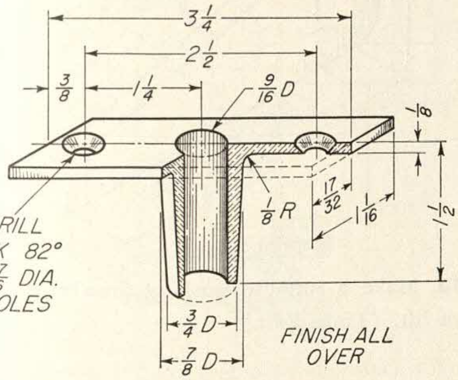
7-3. Make a suitable shop drawing of the aluminum hanger bracket. (Time. 3 hr.)



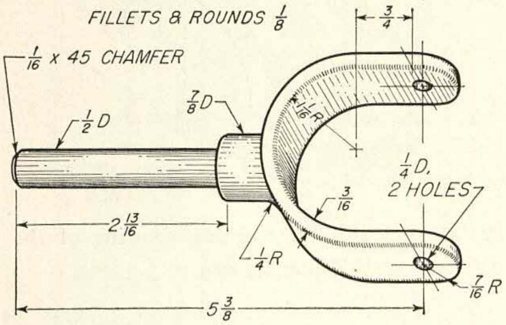
7-4. Redraw the given views of the cast-iron pulley. Redimension properly, decimally.



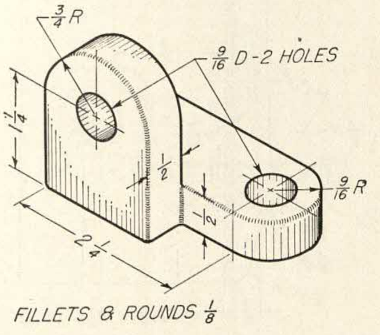
7-5. Transfer to the drawing sheet the two views of the steel clevis, using the scale shown as ⅛-in. divisions. The holes are drilled and counterbored. Dimension your drawing to serve as a working drawing for the shop. (Time. 2 hr.)



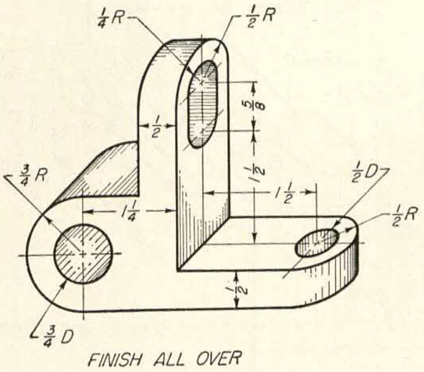
7-6. Make a suitable working drawing of the brass oarlock mounting. Portions of the object have been cut away to show the shape of the holes. (Time. 2 hr.)



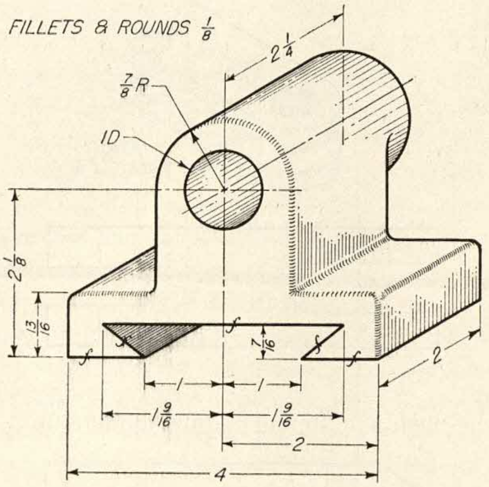
7-7. Make a suitable working drawing of the brass oarlock. (Time. 2 hr.)



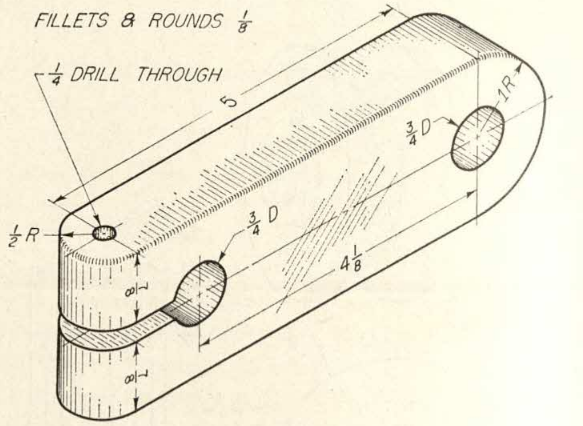
7-8. Make a suitable working drawing of the cast-iron rod support. (Time. 2 hr.)



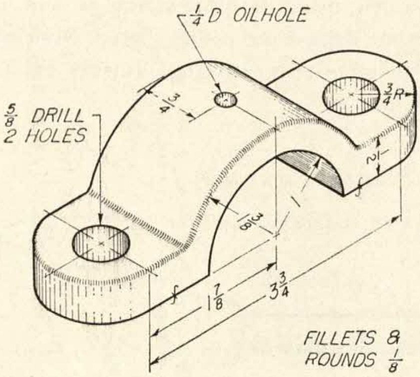
7-9. Make a suitable working drawing of the cast-iron rod guide. (Time. 2½ hr.)



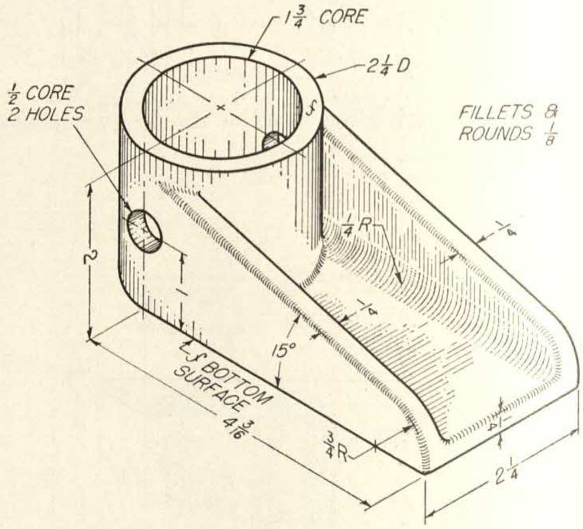
7-10. Make a suitable working drawing of the cast-iron rod guide. (Time. 1½ hr.)



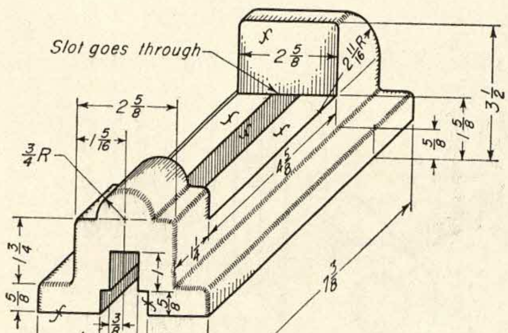
7-11. Make a suitable working drawing of the steel clamp. (Time. 1½ hr.)



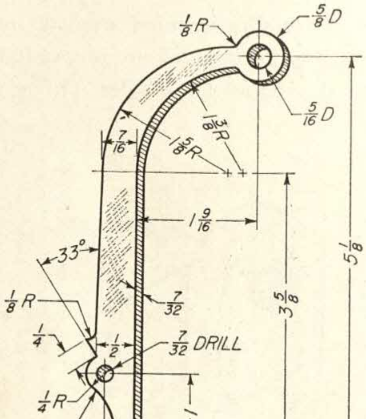
7-12. Make a suitable working drawing of the cast-iron bearing cap. (Time. 1½ hr.)



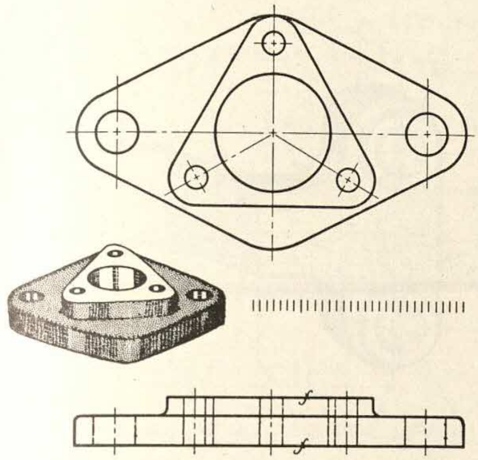
7-13. Make a suitable working drawing of the steel chassis lift. (Time. 2 hr.)



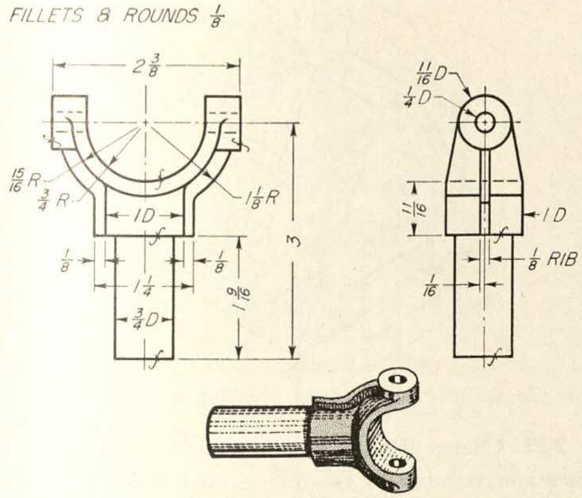
7-14. Make a suitable working drawing of the steel vise jaw. (Time. 3 hr.)



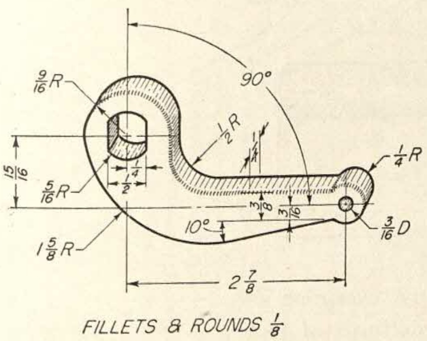
7-15. Make a suitable working drawing of the brass lever. (Time. 2 hr.)



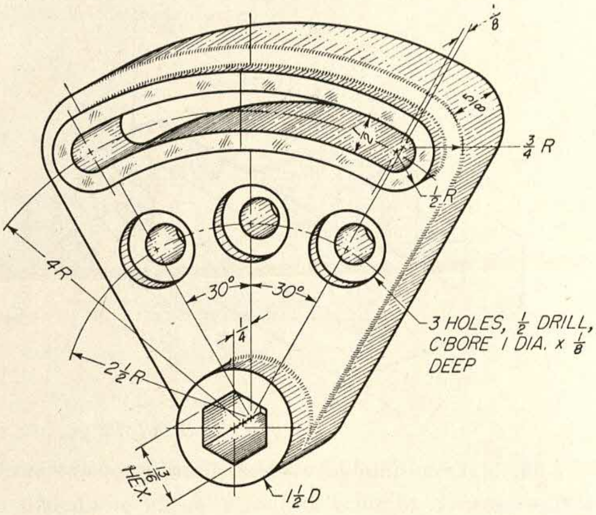
7-16. Transfer the two views of the cast-iron base to your drawing sheet, adding the notes and dimensions required for a suitable working drawing. The scale shown on the illustration indicates ⅛-in. divisions. (Time. 2 hr.)



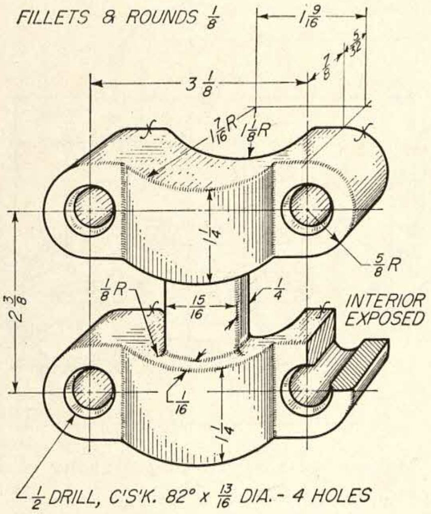
7-18. Redraw the given views of the steel yoke, rearranging the dimensions you feel are improperly placed so as to satisfy the principles of proper dimensioning procedure, and present a suitable working drawing. (Time. 2 hr.)



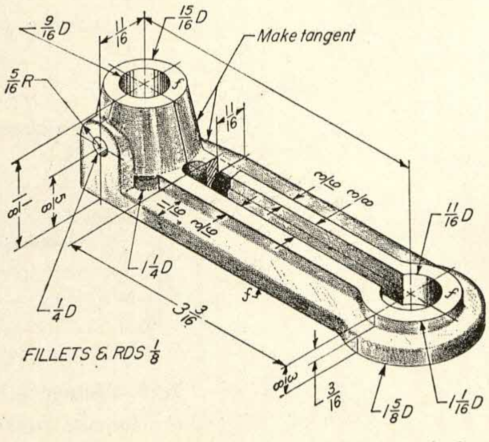
7-20. Make a suitable working drawing of the brass brake arm. (Time. 3 hr.)



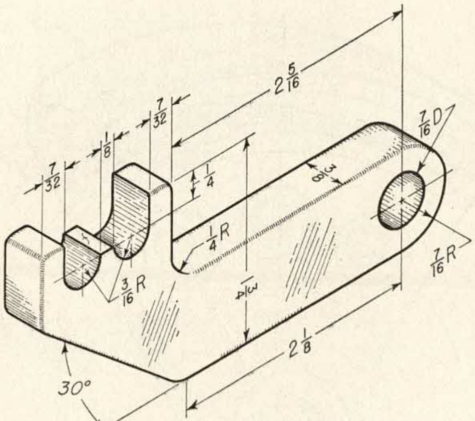
7-17. Make a suitable working drawing of the cast-iron adjusting bracket. (Time. 4 hr.)



7-19. Make a suitable working drawing of the cast-iron clamp bracket. (Time. 3 hr.)

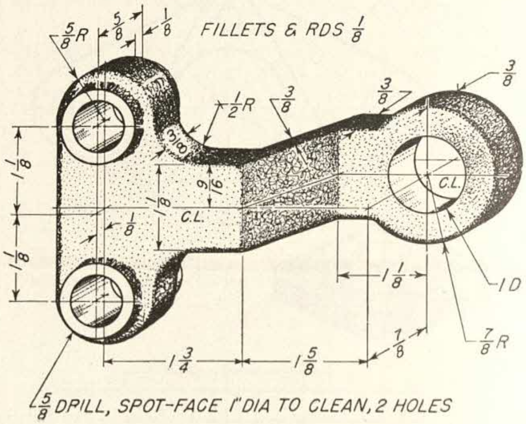


7-21. Make a suitable working drawing of the steel tool support. (Time. 4 hr.)



FILLETS & ROUNDS 1/8

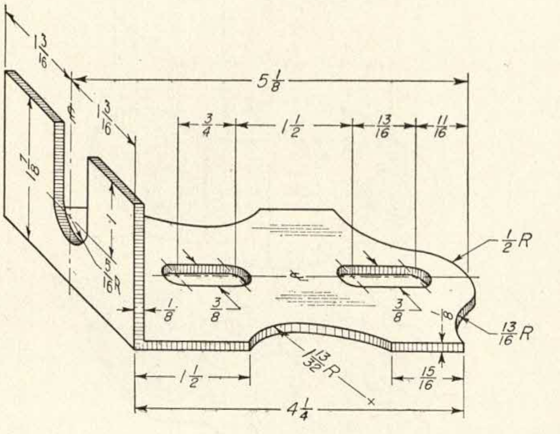
7-22. Make a suitable working drawing of the steel adjusting lever. (Time. 2 hr.)



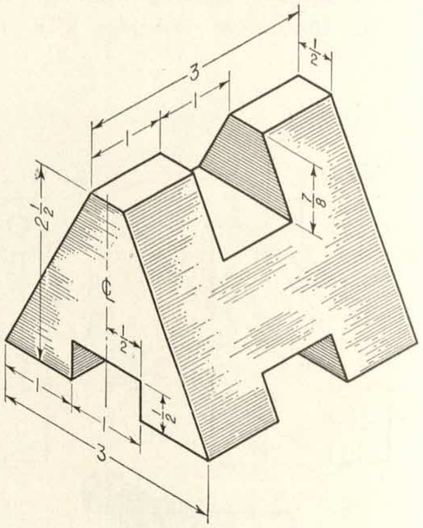
FILLETS & RDS 1/8

5/8 DRILL, SPOT-FACE 1" DIA TO CLEAN, 2 HOLES

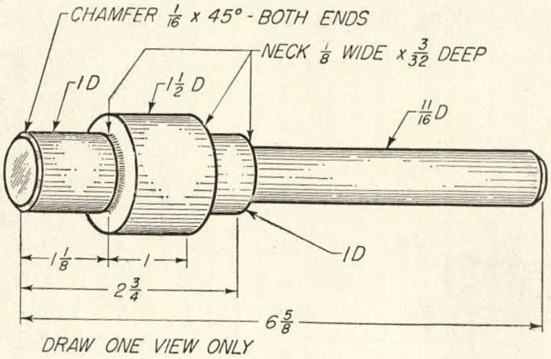
7-23. Make a suitable working drawing of the wrought-iron-frame shaft support. (Time. 3 hr.)



7-24. Make a suitable working drawing of the steel hinge. (Time. 2 hr.)

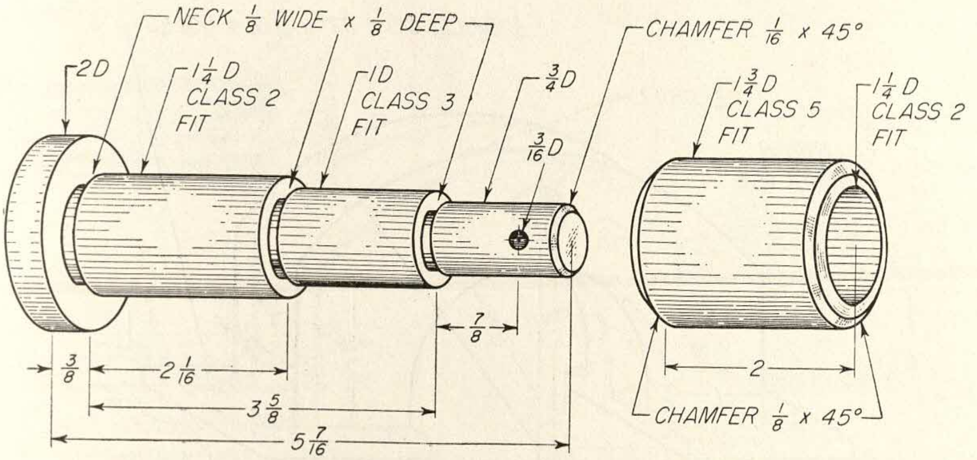


7-25. Change the fractional dimensions to decimal dimensions reduced to two places, and make a suitable working drawing of the wedge block. (Time. 2 hr.)

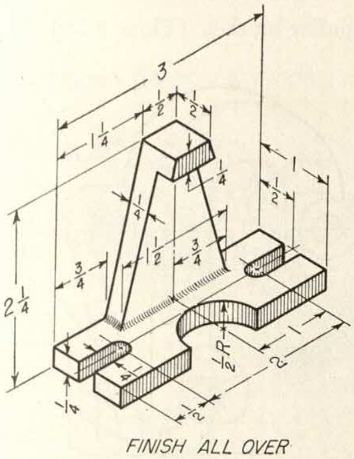


DRAW ONE VIEW ONLY

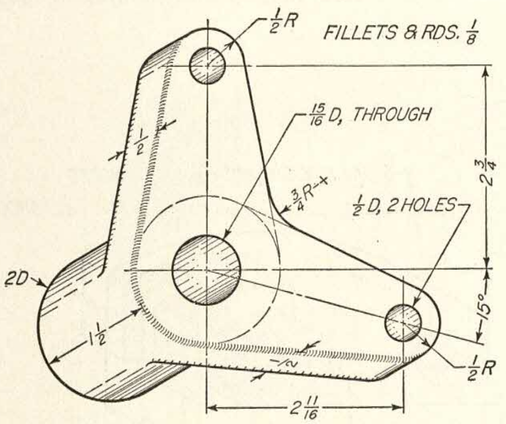
7-26. Change all dimensions with the exception of those for the necks and chamfers to decimals of four places, and make a suitable working drawing of the steel shaft. (Time. 1¾ hr.)



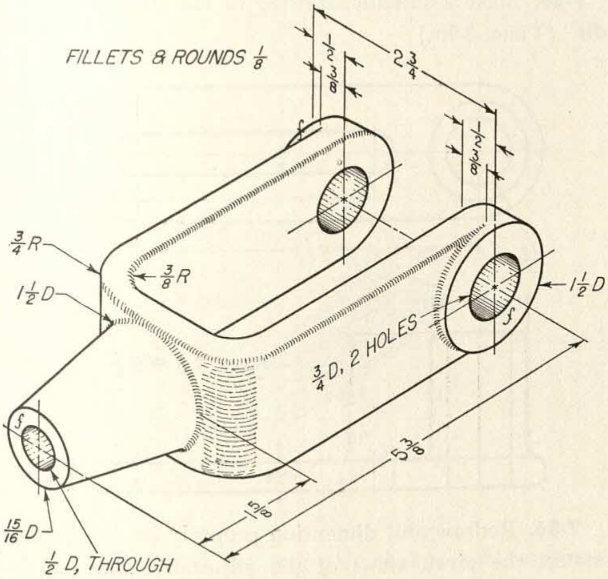
7-27. Make suitable working drawings of the steel stud shaft and bronze bushing on the same sheet. Change all dimensions with the exception of those for the necks and chamfers to decimals of four places. Compute the dimensions for the classes of fits from the tables in the Appendix. (Time. 4½ hr.)



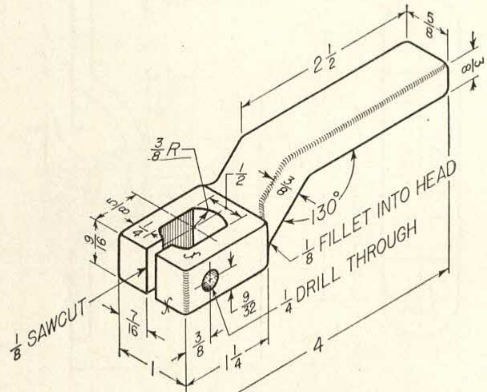
7-28. Make a suitable working drawing of the brass lock base. (Time. 2½ hr.)



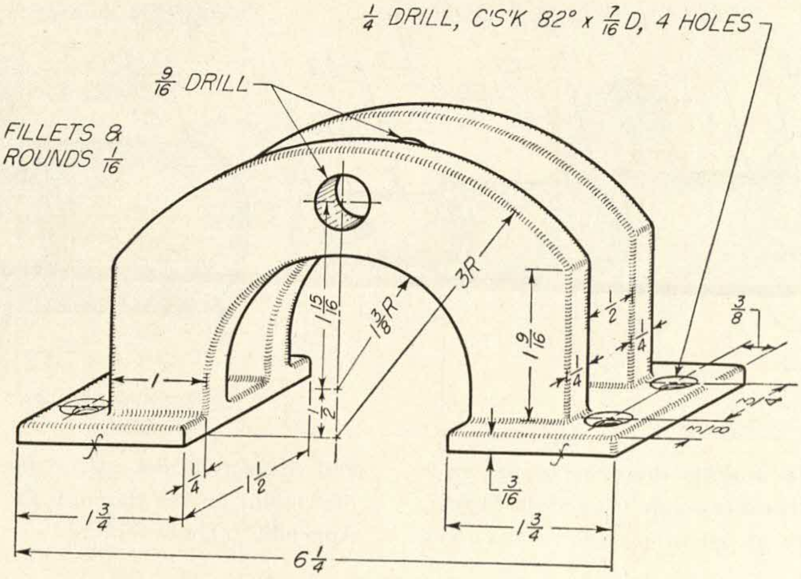
7-29. Make a suitable working drawing of the cast-iron rocker arm. (Time. 2½ hr.)



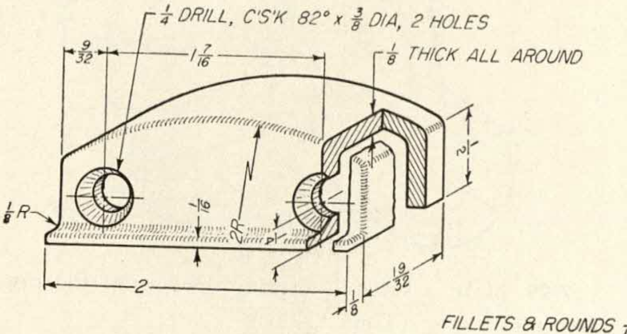
7-30. Make a suitable working drawing of the steel clevis. (Time. 2½ hr.)



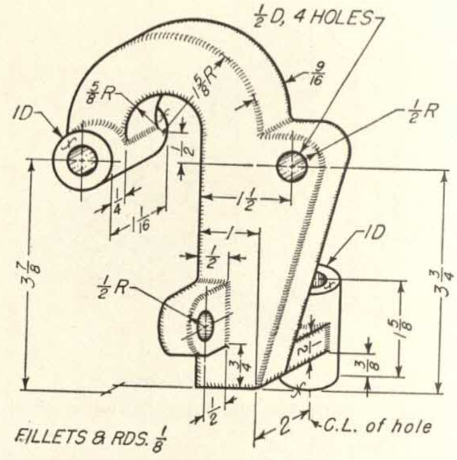
7-31. Make a suitable working drawing of the brass valve handle. (Time. 2½ hr.)



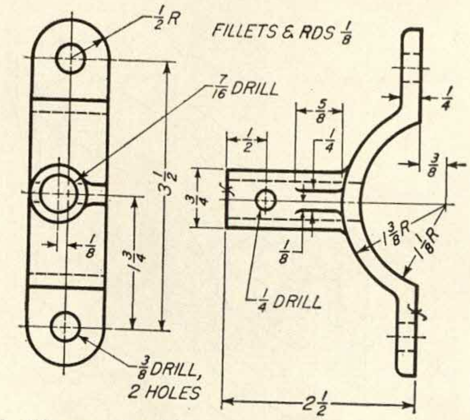
7-32. Make a suitable working drawing of the aluminum pulley bracket. (Time. 3 hr.)



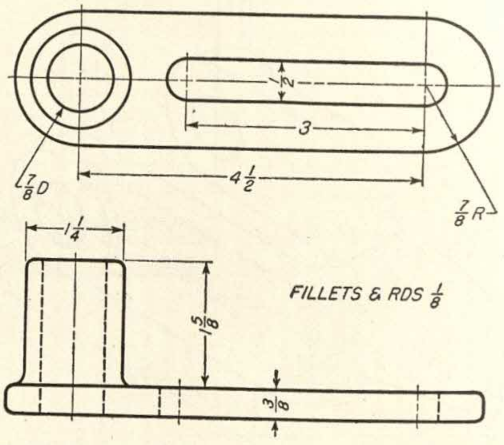
7-33. Make a suitable working drawing of the brass lock catch. (Time. 2 hr.)



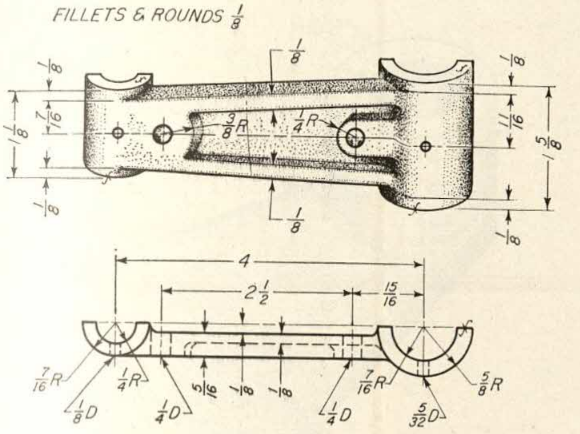
7-34. Make a suitable drawing of the steel arm spindle. (Time. 3 hr.)



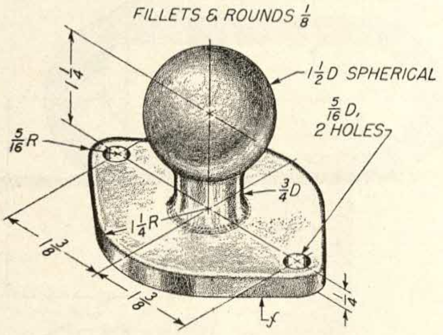
7-35. Change the dimensions of the steel base to satisfy good practice in decimal dimensioning. (Time. 2 hr.)



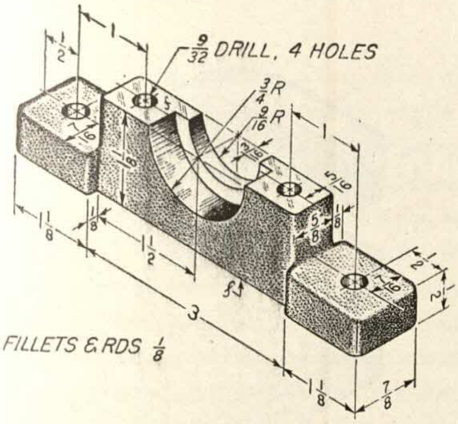
7-36. Redraw and dimension properly in the decimal system the given views of the adjustable shaft guide. (Time. 2 hr.)



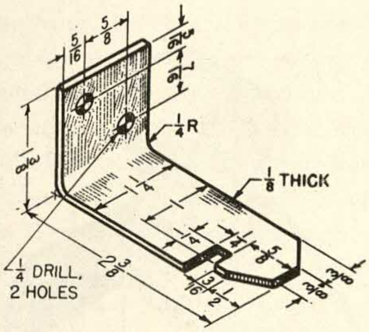
7-37. Using the given orthographic as a front view and the pictorial above it to find other needed dimensions, make a decimal-system working drawing for the cast-iron bearing clamp. (Time. 2½ hr.)



7-38. Make a decimal-system working drawing of the brass knob. (Time. 2 hr.)

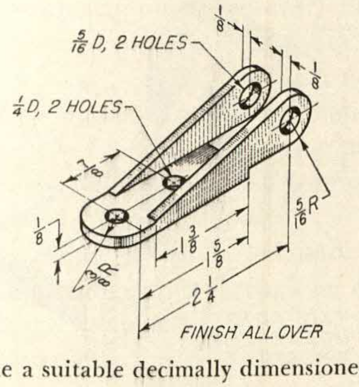


7-39. Make a suitable working drawing of the cast-iron bearing base. (Time. 3½ hr.)

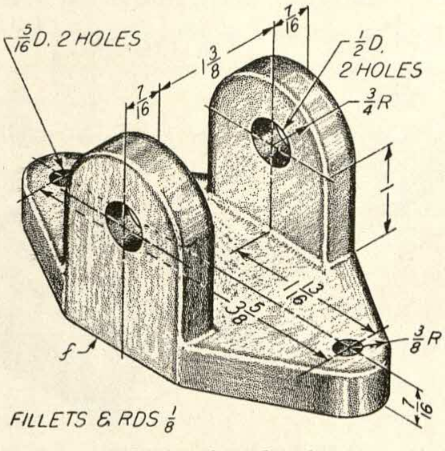


7-40. Make a suitable working drawing of the steel latch. (Time. 2 hr.)

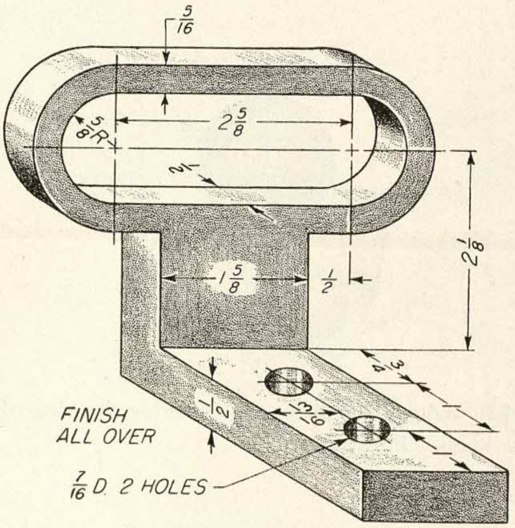
Problems 7-42 to 7-47. Make working drawings (dimension fractionally or decimally) of the following:



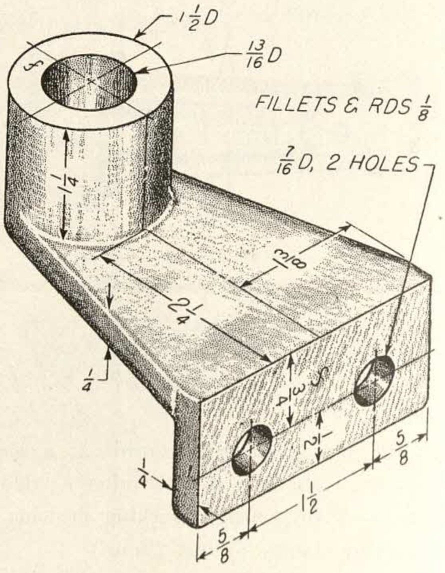
7-41. Make a suitable decimally dimensioned working drawing of the steel cable clip.



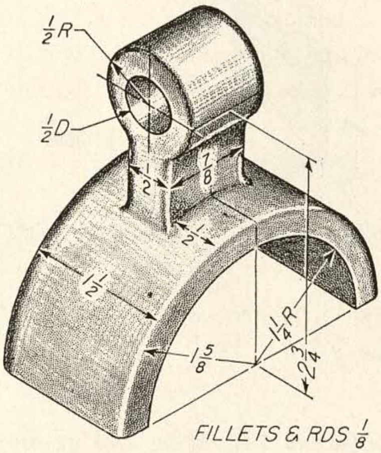
7-42. Cast-iron bracket.



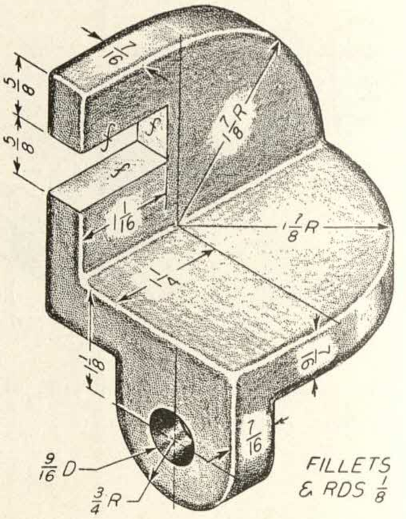
7-43. Steel anchor.



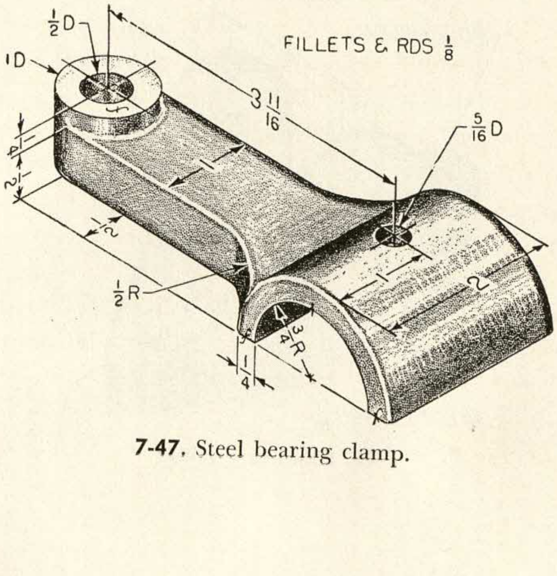
7-44. Steel shaft guide.



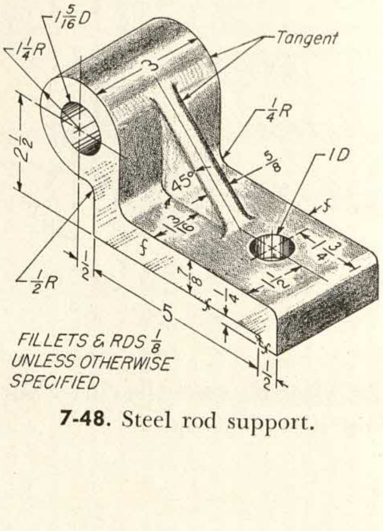
7-45. Steel cable anchor.



7-46. Aluminum belt guide.



7-47. Steel bearing clamp.



7-48. Steel rod support.

Chapter 8

SECTIONING AND CONVENTIONAL PRACTICES

Sometimes an object is so complicated that its ordinary orthographic representation would result in a bewildering conglomeration of hidden lines representing hidden details. The draftsman can avoid this confusing situation by making a drawing "in section" which reveals the interior features while preserving a portion of the significant external lines of the piece. To obtain a section view, an imaginary cutting plane is passed through the object in a selected position and direction. The portion shown in the section drawing is the part of the object that would be seen if the segment nearest the observer had been cut away and discarded. The other views are drawn in the ordinary manner, the only change being the inclusion of the symbolic cutting-plane line, which shows the position of the imaginary cutting plane.

A longitudinal section cuts an object lengthwise; a cross section cuts an object crosswise. The former is termed a "sectional view"; the latter is known as a "cross section." Section views are helpful in detail drawing and are practically indispensable in assembly drawing, where the great number of hidden lines encountered would defeat any worthwhile purpose of the representations.

8-1. Full sections. When a longitudinal imaginary cutting plane extends through an entire object showing the whole object in section, as in Fig. 8-1, the result is known as a "full section." In the front view, note that not only the cut surface but also any visible lines behind the sectioning plane are shown. Note also that the top view, with the exception of the inclusion of the cutting-plane line, is represented in the ordinary manner.

8-2. The cutting-plane line. The construction of the symbolic cutting-plane line is shown in Fig. 8-2. It is placed on the view that is adjacent to the section view and indicates the path of the cutting plane. The line consists of two short and one long dash repeated as required for its length, terminating in arrows that point in the direction in which the object was viewed when the section was taken. A simple way to avoid confusion is to remember that the arrows always point away from the discarded portion of the object. If only one section view appears on the drawing sheet and the position of the cutting-plane line is obvious or cannot be mistaken, it may be omitted on that sheet. If two or more section views appear on the same sheet, however, the cutting-plane lines must be shown and identified by letters placed at the extremities below or behind the arrows (see Figs. 8-3 and 8-17). These letters are capitals and should be the largest letters on the drawing (1/4 to 3/8 in. high). It may not always be possible or desirable to place a section view on the same sheet as the view showing its cutting-plane line. Therefore, when a cutting-plane line identifies a section view on another sheet, a fraction is used showing in the numerator the letter of the section and in the de-

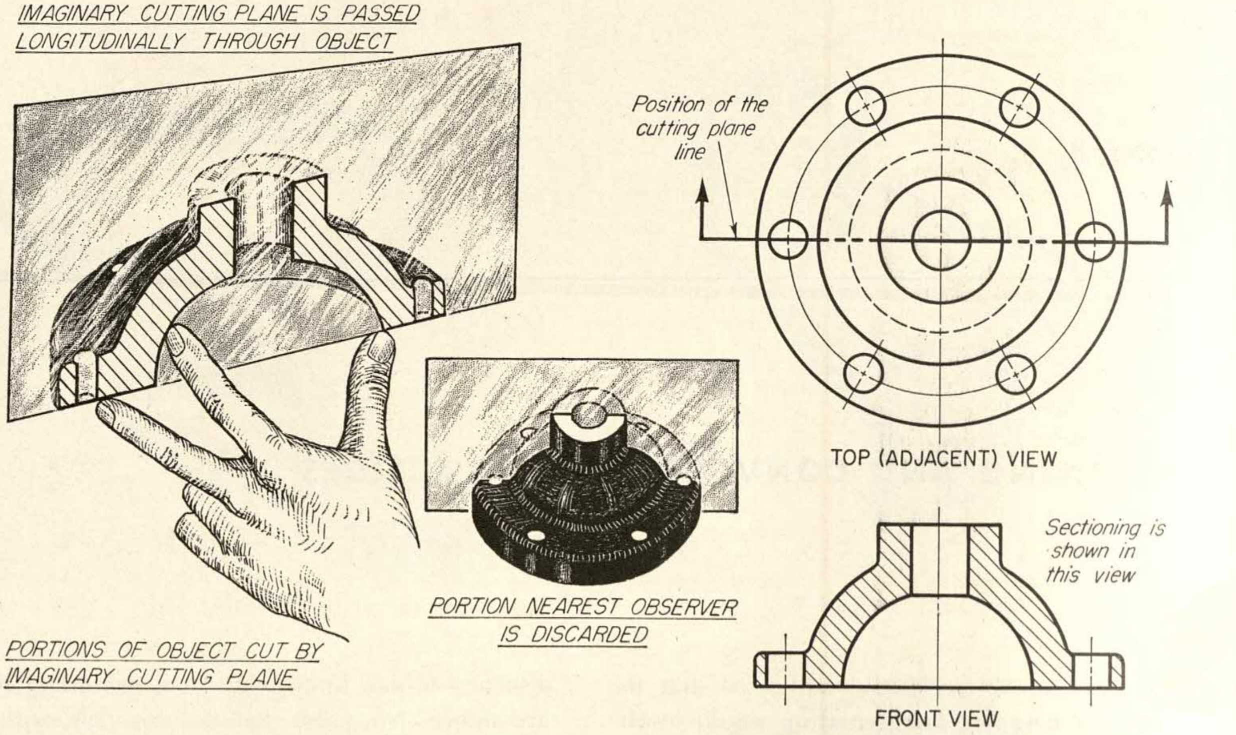

IMAGINARY CUTTING PLANE IS PASSED LONGITUDINALLY THROUGH OBJECT
Position of the cutting plane line
TOP (ADJACENT) VIEW
Sectioning is shown in this view
PORTION NEAREST OBSERVER IS DISCARDED
PORTIONS OF OBJECT CUT BY IMAGINARY CUTTING PLANE
FRONT VIEW

Fig. 8-1. The full section.

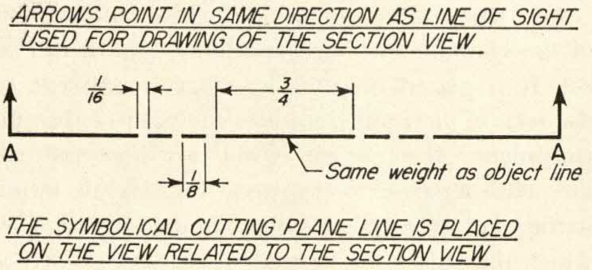

ARROWS POINT IN SAME DIRECTION AS LINE OF SIGHT USED FOR DRAWING OF THE SECTION VIEW
1/16
3/4
A
A
Same weight as object line
1/8
THE SYMBOLICAL CUTTING PLANE LINE IS PLACED ON THE VIEW RELATED TO THE SECTION VIEW

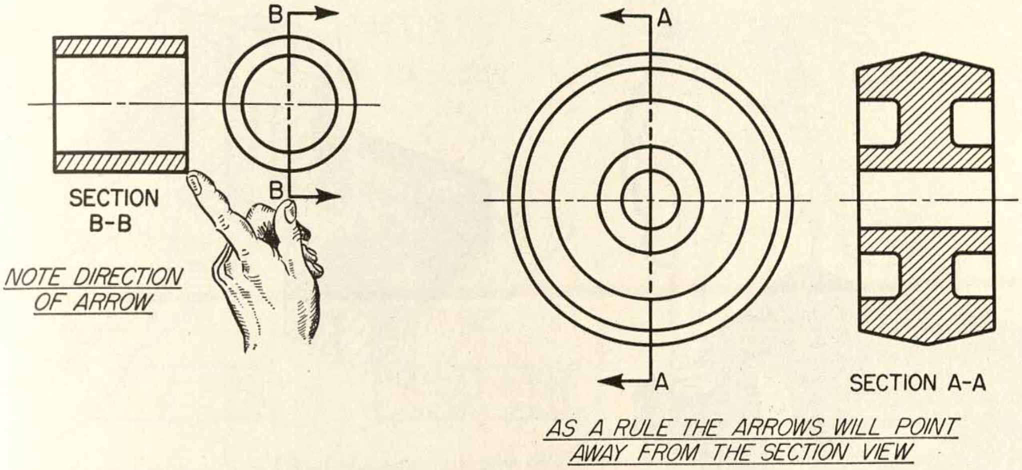
Fig. 8-2. The cutting-plane line.

nominator the number of the sheet where the section view may be located. The fraction is placed in a circle at the intersection of the line and the shaft of the arrow, as shown in Fig. 8-4. When a cutting-plane line and a center line coincide in the ordinary view, the cutting-plane line takes precedence and is the one shown on that view (see Fig. 8-12).

8-3. Offset sections. A full-section cutting plane need not always pass through the main axis or center line of an object. Its direction may be changed (that is, offset) in order to show other desired features and details. When an offset full section is drawn, the section view shows no lines to indicate the break, or offsetting, of the imaginary cutting plane. However, the true course of the cutting plane is always shown in the adjacent or related view by the symbolic cutting-plane line. Figures 8-4 and 8-5 illustrate the use of an offset section plane.

8-4. Invisible lines. Ordinarily, all contours of the forms exposed, including the edges of the parts severed by the cutting plane, are shown in the section view. Since the prime reason for drawing a section view is to show the internal forms and features of a part, hidden lines should not be shown in the drawing unless they are absolutely necessary for further clarification or unless their presence is indispensable for dimensioning purposes. (A section view may be used for dimensioning just like any ordinary view.) If the use of several hidden lines will save the labor of producing another complete view, the draftsman should use his own judgment in the matter. In Fig. 8-1, for example, no hidden lines are shown in the section view (front view). See discussion in Sec. 7-24 also.

8-5. Section lining. All section views are distinguishable by what is known as "section lining" (sometimes erroneously called "crosshatching"). In section lining, parallel lines are drawn across all surfaces cut by the sectioning plane. Since the appearance of a drawing may be marred by poor section lining, this should be done very carefully.



NOTE DIRECTION OF ARROW

AS A RULE THE ARROWS WILL POINT AWAY FROM THE SECTION VIEW

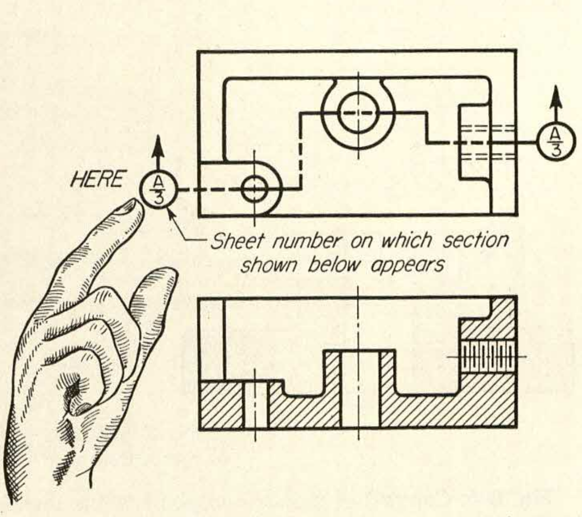
Fig. 8-3. Use of the cutting-plane line.

8-6. Section-lining technique. The section lining for each individual part must always be drawn in the same direction—with the same spacing and angle—in all views showing that part in section, whether standing alone or shown in assembly with other pieces. A single piece is sectioned with sharp thin lines about $\frac{1}{16}$ in. apart, with the lines making an angle of 45° with the horizontal (see Fig. 8-9). In the case of small pieces, the pitch (spacing) may be reduced to $\frac{1}{32}$ in., while for large objects the section lines may be as much as $\frac{1}{8}$ in. apart. There is no set rule governing the amount of pitch or the size of the angle. The size and contour of the part will often suggest the best spacing and angle to employ. (See also Figs. 13-1 and 13-2.)

Section lining requires much patience and care on the part of the draftsman, since, in addition to having to maintain uniform pitch "by eye," he must make the lines regular and of even weight, with sufficient contrast between them and the lines of the object. The left-hand portion of Fig. 8-6 shows the pleasing pattern obtained when an even and proper pitch is combined with uniform lines that make a correct contrast with the outlines of the cut portion and the other contour lines of the object. The right side of the figure shows the ruinous effect of poorly spaced and executed section lining. When objects whose dominant outlines are parallel to the natural 45, 30, and 60° angles are encountered, a 75 or 15° slant, or any odd angle, should be employed to avoid bizarre effects such as grooving and other distortions (see Fig. 8-7).

8-7. Outline sectioning. For very large areas, it is permissible to show section lines just within the boundary of the surface shown sectioned, leaving the interior portions untouched. An example of outline sectioning is given in Fig. 8-8.

8-8. Sections in assembly. In assembly drawings, all portions of the same piece are always shown (in all views) with the section lining running in the same direction, with the lines all the same weight and the same distance apart. The section lining of the part adjacent runs in the opposite direction. If two pieces are shown in assembly, the lines of each piece are drawn at 45° angles running in opposite directions (see Fig. 8-9). When three or more pieces appear in assembly, angles of 30, 60, or even 15° may be employed (see Fig. 8-9*c* and *d*), or the pitch of the



Sheet number on which section shown below appears

Fig. 8-4. Identification for section views. (ASA Z14.)

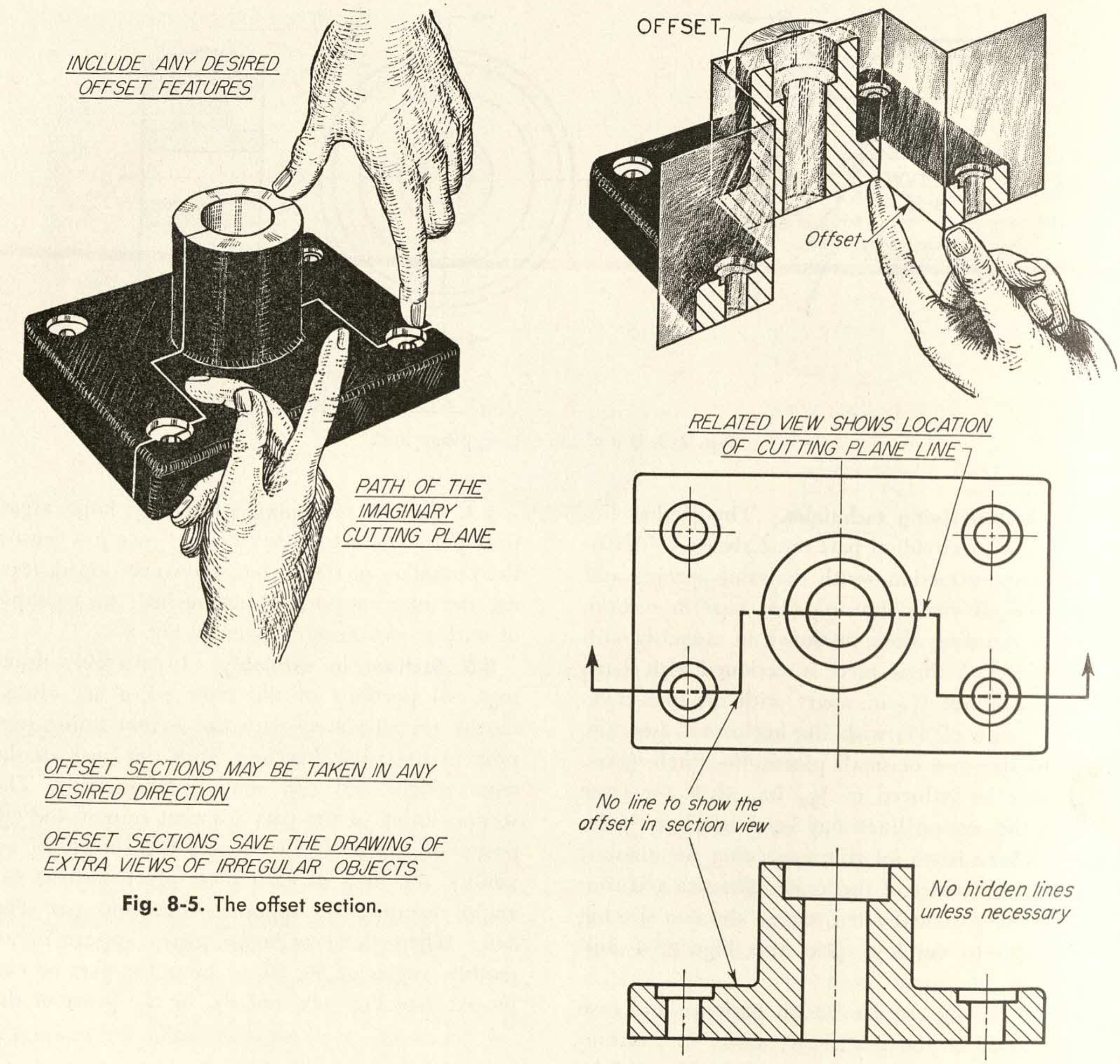

INCLUDE ANY DESIRED OFFSET FEATURES
PATH OF THE IMAGINARY CUTTING PLANE
OFFSET SECTIONS MAY BE TAKEN IN ANY DESIRED DIRECTION
OFFSET SECTIONS SAVE THE DRAWING OF EXTRA VIEWS OF IRREGULAR OBJECTS
OFFSET
Offset
RELATED VIEW SHOWS LOCATION OF CUTTING PLANE LINE
No line to show the offset in section view
No hidden lines unless necessary

Fig. 8-5. The offset section.

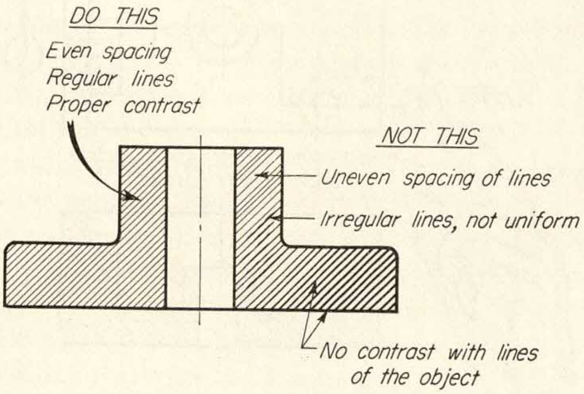


Fig. 8-6. Contrast of proper and poorly done section lining.

section lining may be varied (that is, drawn slightly closer together or farther apart depending on the size of the piece), taking care that the lines do not run parallel to the principal lines of the part being sectioned. Adherence to these few rules will prevent the possibility of an observer confusing one piece with another. (See also Figs. 13-1, 13-2, and 13-10.)

8-9. Section code for different materials. Different kinds of section lining may be used to indicate various materials (steel, cast iron, brass or copper, the white metals, etc.). When a drawing shows only a single detail, the exact composition of the object is shown in the title block and *code*

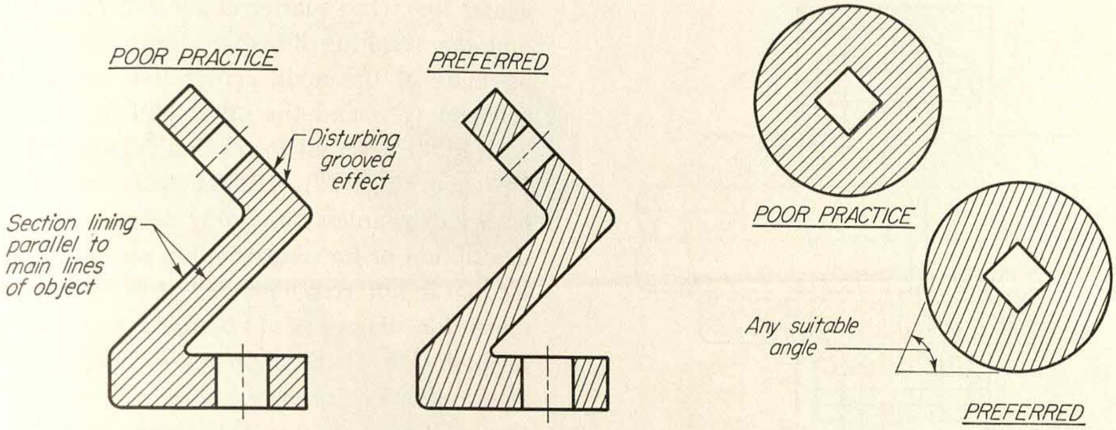

POOR PRACTICE
PREFERRED
Disturbing grooved effect
Section lining parallel to main lines of object
POOR PRACTICE
Any suitable angle
PREFERRED

Fig. 8-7. Avoid bizarre effects in section lining.

section lining is not necessary. Where several pieces are shown in a section assembly, however, it may be helpful to identify the different parts and materials by using the sectioning code approved by the American Standards Association (which is shown in the Appendix). Code sectioning is not in general use in industry, however, and in most shops its use is determined by the chief draftsman. The customary practice is to use the section lining for cast iron for all objects and indicate the exact composition in the title block or bill of materials (see Figs. 8-9 and 8-13, for example).

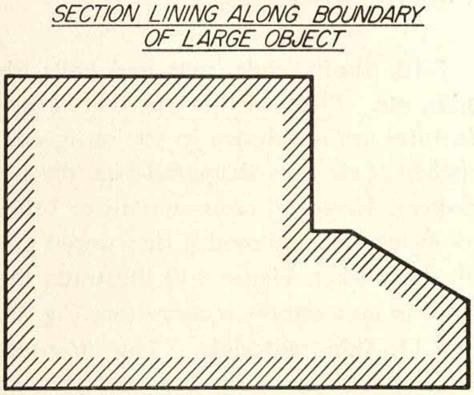


Fig. 8-8. Outline sectioning.

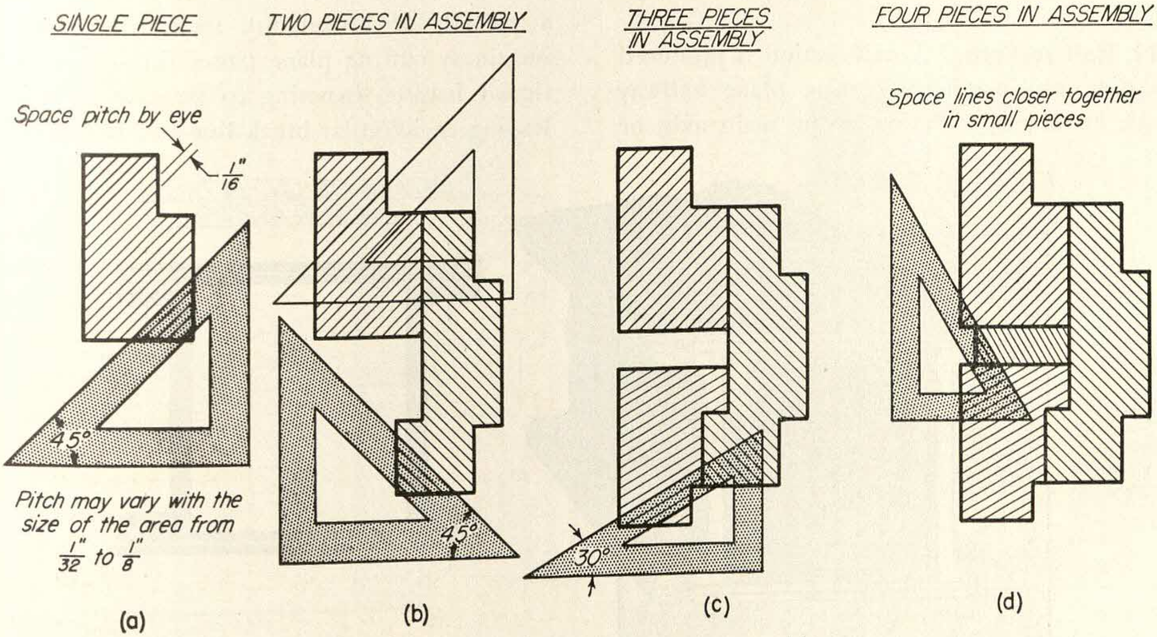


Fig. 8-9. Section lining for parts in assembly.

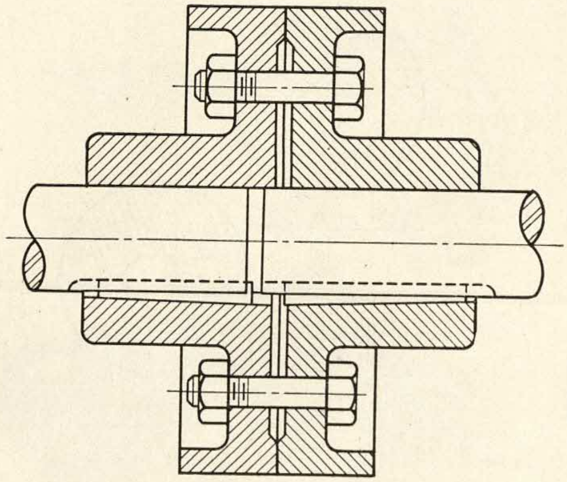


Fig. 8-10. Shafts, keys, bolts, and nuts in sectional view. (*From ASA Z14.1—1946.*)

8-10. Shafts, rods, nuts and bolts, rivets, keys, pins, etc. Pieces of this type that have no internal features are not drawn in section if seen in profile (when their axes lie parallel to the plane of the paper). However, cross sections or broken-out sections may be employed if they would prove helpful to the worker. Figure 8-10 illustrates their appearance in an assembly section. (See Fig. 13-2 also.)

8-11. Thin materials. The cross-section views of structural steel, sheet-metal forms, gaskets, and other thin materials are shown in solid black. If two or more thin pieces are adjacent to each other, a white line should separate the parts (see Fig. 8-11).

8-12. Half sections. A half section is produced by passing an imaginary cutting plane halfway through an object, stopping at the main axis, or center line. One-quarter of the object is discarded, and the resulting drawing shows the portion on one side of the main center line as an ordinary external view and the other half as a section revealing the internal forms and features of the object (see Fig. 8-12). Hidden lines are omitted in both halves unless absolutely necessary for further description or for dimensioning purposes. The half section is not recommended if it is necessary to dimension diameters of circular forms that extend on both sides of the main center line, since the dimensioning can rarely be done without the addition of hidden lines in the portion that shows the external features. In the case of assembly drawings, however, where often the only dimensions required are reference over-alls and those between main center lines, it is very advantageous to the draftsman to be able to show both the external and internal appearance of a bisymmetrical group in assembly (Fig. 8-13). Note also in Figs. 8-12 and 8-13 that a center line is used at the center of the sectioned view, for if a center line and a cutting-plane edge coincide in a section view, the center line is shown instead of a solid object line, since the edge represents only the imaginary cutting plane and the parts themselves are not actually to be severed in the machine shop.

8-13. Broken-out sections. In cases where only isolated details or features need be shown and a full or half section would serve no useful purpose, a partial, or broken-out, section is used. The imaginary cutting plane passes through some particular feature, exposing its interior to view and leaving an irregular break line as a boundary (see

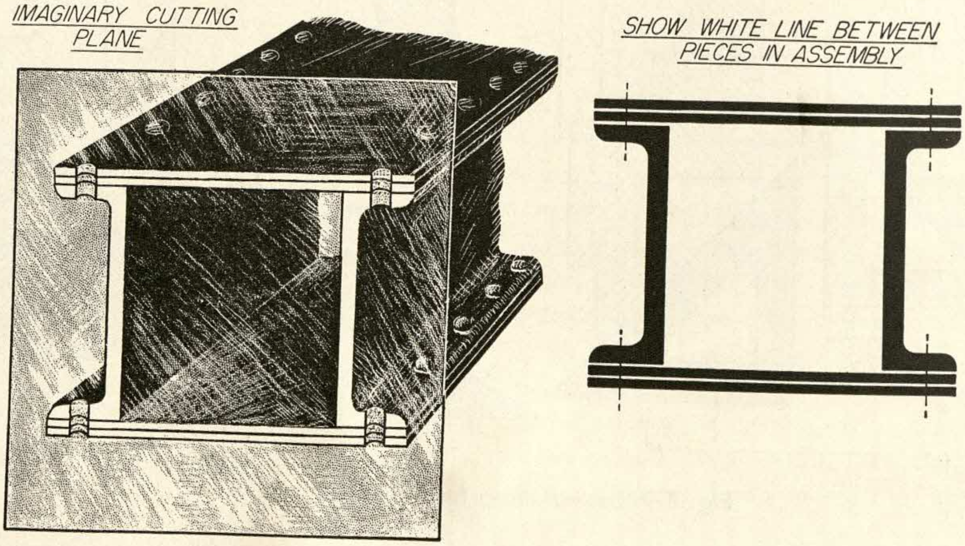


Fig. 8-11. Thin materials in section.

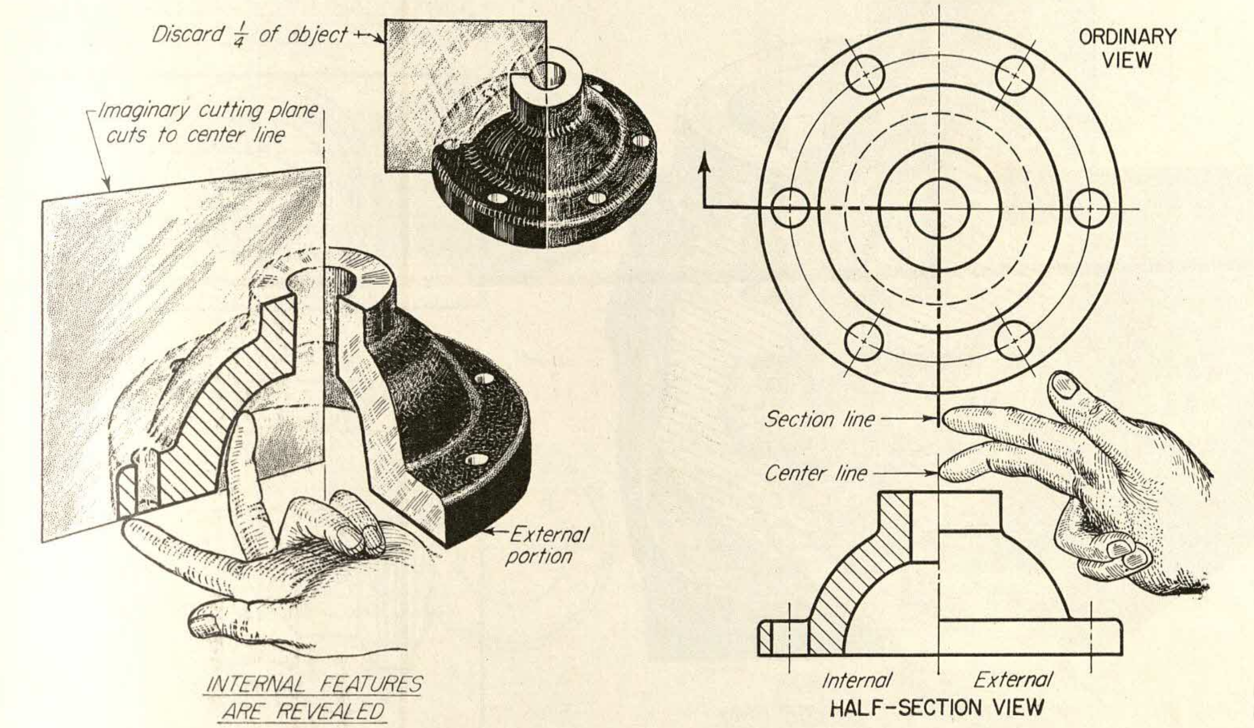

Discard $\frac{1}{4}$ of object
Imaginary cutting plane cuts to center line
External portion
INTERNAL FEATURES ARE REVEALED
ORDINARY VIEW
Section line
Center line
Internal
External
HALF-SECTION VIEW

Fig. 8-12. The half section.

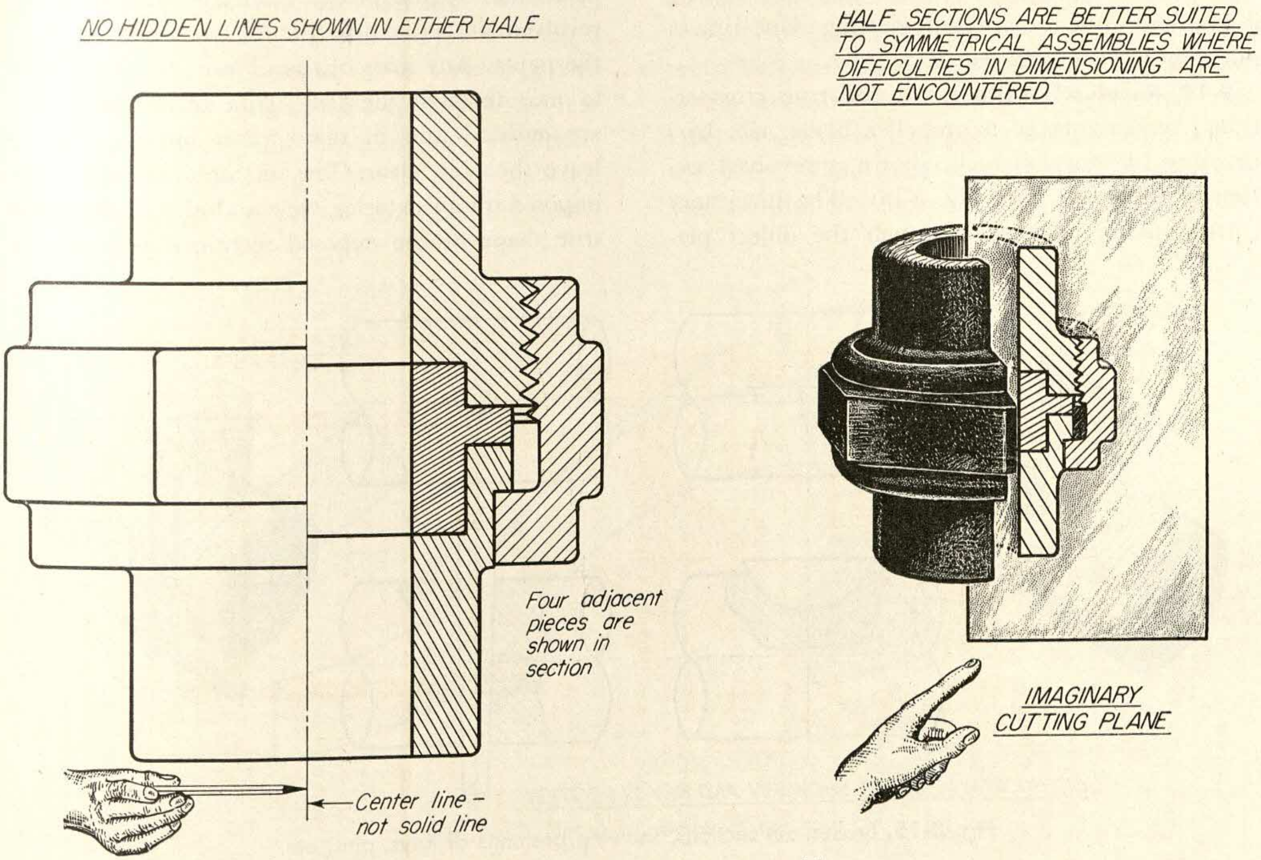

NO HIDDEN LINES SHOWN IN EITHER HALF
HALF SECTIONS ARE BETTER SUITED TO SYMMETRICAL ASSEMBLIES WHERE DIFFICULTIES IN DIMENSIONING ARE NOT ENCOUNTERED
Four adjacent pieces are shown in section
IMAGINARY CUTTING PLANE
Center line - not solid line

Fig. 8-13. Half section of an assembly.

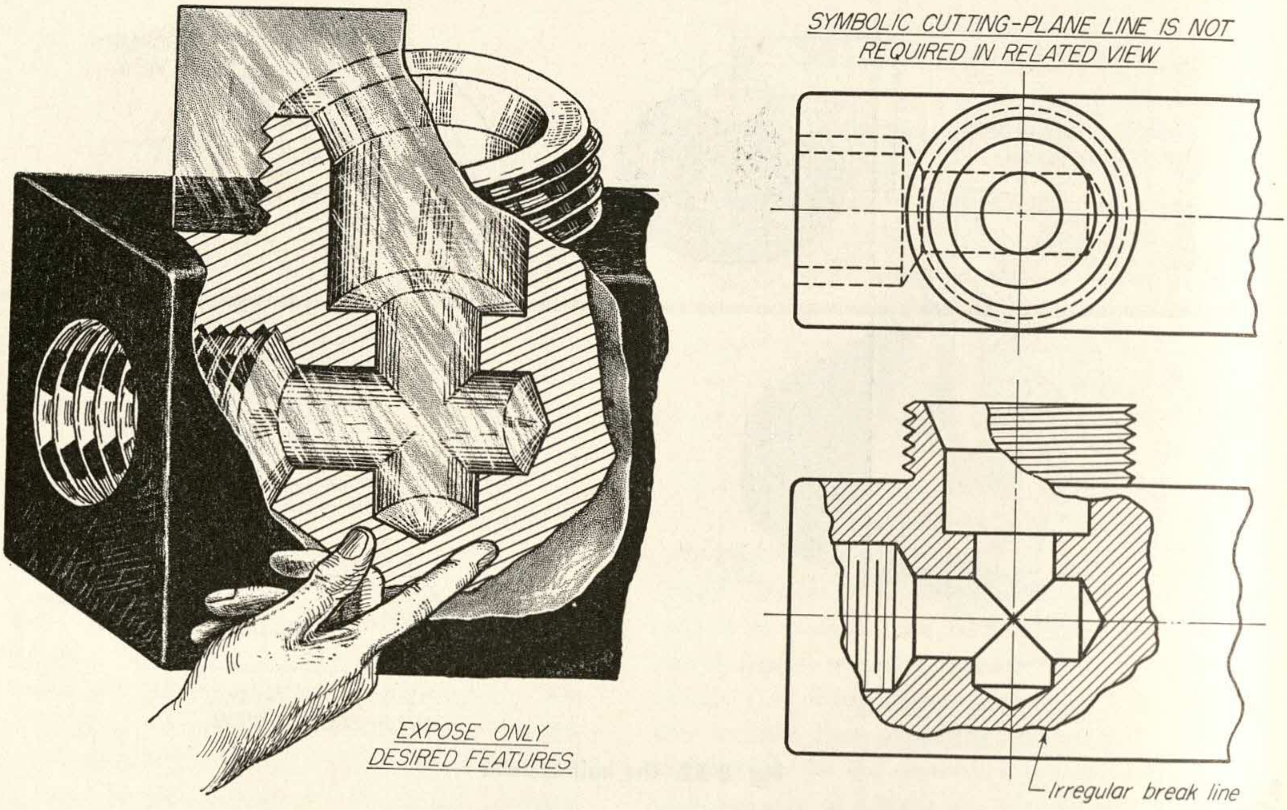

SYMBOLIC CUTTING-PLANE LINE IS NOT REQUIRED IN RELATED VIEW
EXPOSE ONLY DESIRED FEATURES
Irregular break line

Fig. 8-14. A broken-out section.

Figs. 8-14, 8-15, and 13-2). No further identification is required, and the symbolic cutting-plane line is not shown in the adjacent view.

8-14. Revolved sections. If the true cross-sectional appearance of a propeller blade, rib, bar, or other like form is to be shown, a revolved section is employed (see Fig. 8-16). The imaginary cutting plane is passed through the object perpendicular to the profile (longitudinal) axis and revolved on its center line 90° into the plane of the paper. Any lines of the object that might tend to pass through the true-shape cross-section view are omitted and in many cases broken away to leave the view clear. The section is always superimposed on an exterior view and always shows the true shape of the exposed sectioned portion, the

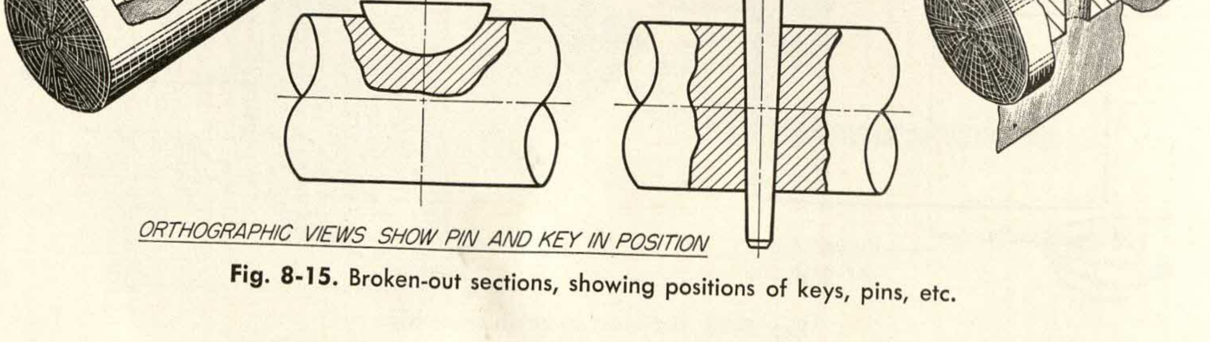
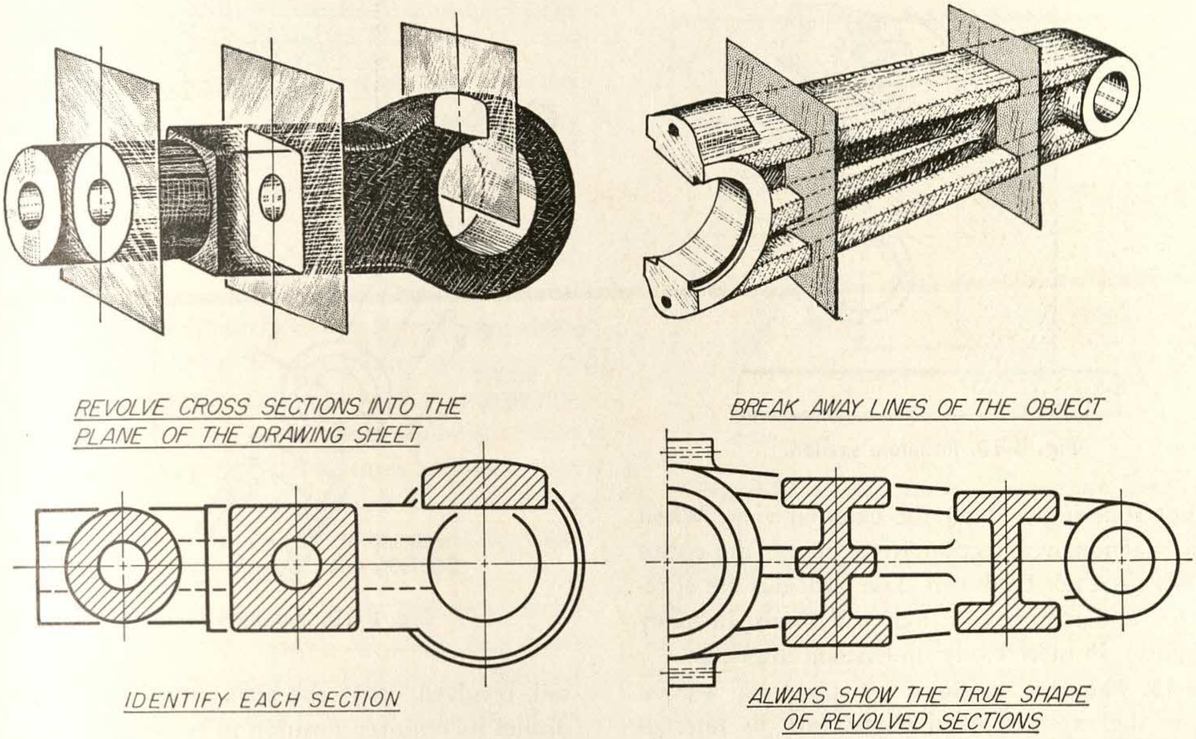


Fig. 8-15. Broken-out sections, showing positions of keys, pins, etc.


REVOLVE CROSS SECTIONS INTO THE PLANE OF THE DRAWING SHEET

BREAK AWAY LINES OF THE OBJECT

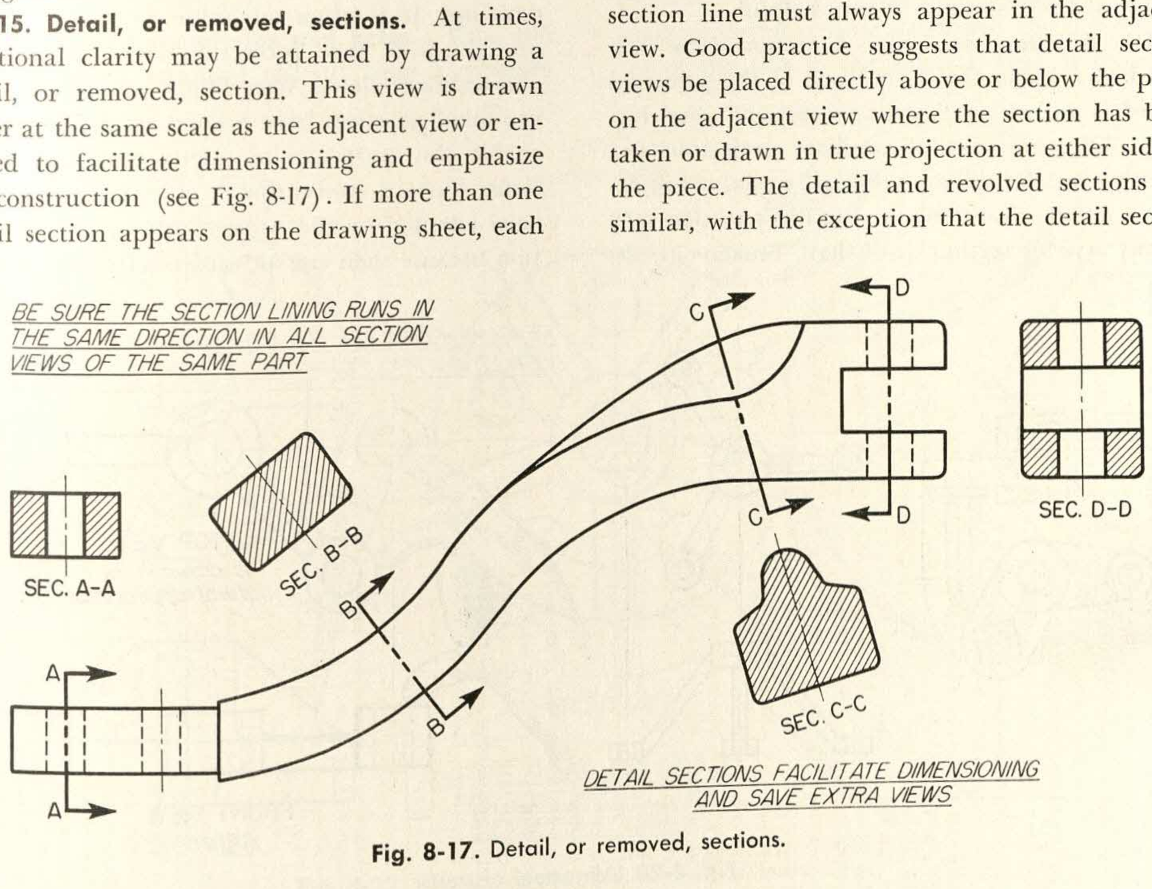
IDENTIFY EACH SECTION

ALWAYS SHOW THE TRUE SHAPE OF REVOLVED SECTIONS

Fig. 8-16. Revolved sections.

direction of the contour lines of the object being disregarded.

8-15. Detail, or removed, sections. At times, additional clarity may be attained by drawing a detail, or removed, section. This view is drawn either at the same scale as the adjacent view or enlarged to facilitate dimensioning and emphasize the construction (see Fig. 8-17). If more than one detail section appears on the drawing sheet, each view must be identified with a note below it, such as "section *AA*," "section *BB*," etc. The symbolic section line must always appear in the adjacent view. Good practice suggests that detail section views be placed directly above or below the point on the adjacent view where the section has been taken or drawn in true projection at either side of the piece. The detail and revolved sections are similar, with the exception that the detail section



BE SURE THE SECTION LINING RUNS IN THE SAME DIRECTION IN ALL SECTION VIEWS OF THE SAME PART

DETAIL SECTIONS FACILITATE DIMENSIONING AND SAVE EXTRA VIEWS

Fig. 8-17. Detail, or removed, sections.

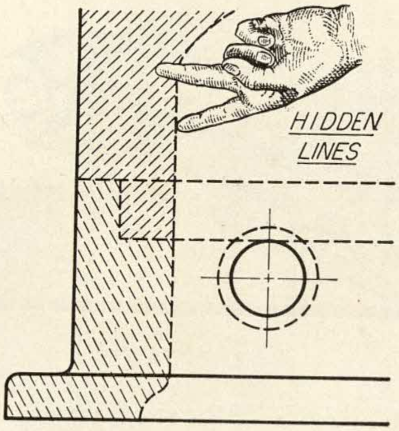


Fig. 8-18. Phantom section.

is not superimposed on the external view. When a partial removed section is employed, the entire object need not be drawn. The judicious use of revolved and removed sections will result, in many instances, in more easily understood drawings.

8-16. Phantom sections. A phantom section shows the exterior of an object with its internal features brought out by hidden section lining (see Fig. 8-18). The phantom section is valuable in showing the relative positions of external and internal adjacent portions or complete parts. It is rarely used but at times is very helpful.

8-17. Auxiliary sections. A section view projected to a plane that is not one of the principal planes is called an "auxiliary section" (see Fig. 8-19). The principles of auxiliary projection and the selection of auxiliary views are explained in detail in Chaps. 9 and 10. An auxiliary section may be any type of section (full, half, broken-out, detail, revolved, etc.); the term auxiliary merely indicates its required position in relation to the view from which it has been projected or in relation to the principal views on the drawing sheet.

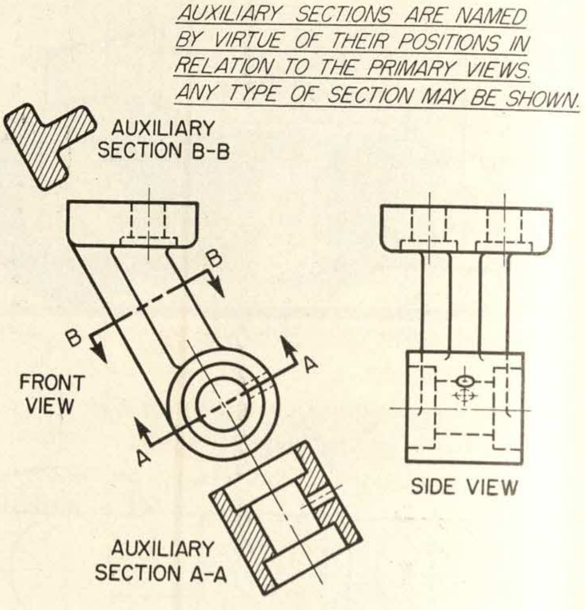

AUXILIARY SECTIONS ARE NAMED BY VIRTUE OF THEIR POSITIONS IN RELATION TO THE PRIMARY VIEWS. ANY TYPE OF SECTION MAY BE SHOWN.
AUXILIARY SECTION B-B
B
B
A
A
FRONT VIEW
SIDE VIEW
AUXILIARY SECTION A-A

Fig. 8-19. Auxiliary sections.

8-18. Conventional practices. To simplify the representation or to avoid distorted or confusing drawings, it is often advisable to violate certain procedures of true projection for both sectional and ordinary views. Accordingly, a number of conventional practices have become established which enable the draftsman to clarify certain presentations. Various conventional procedures have now been adopted by the American Standards Association because their use aids materially in producing

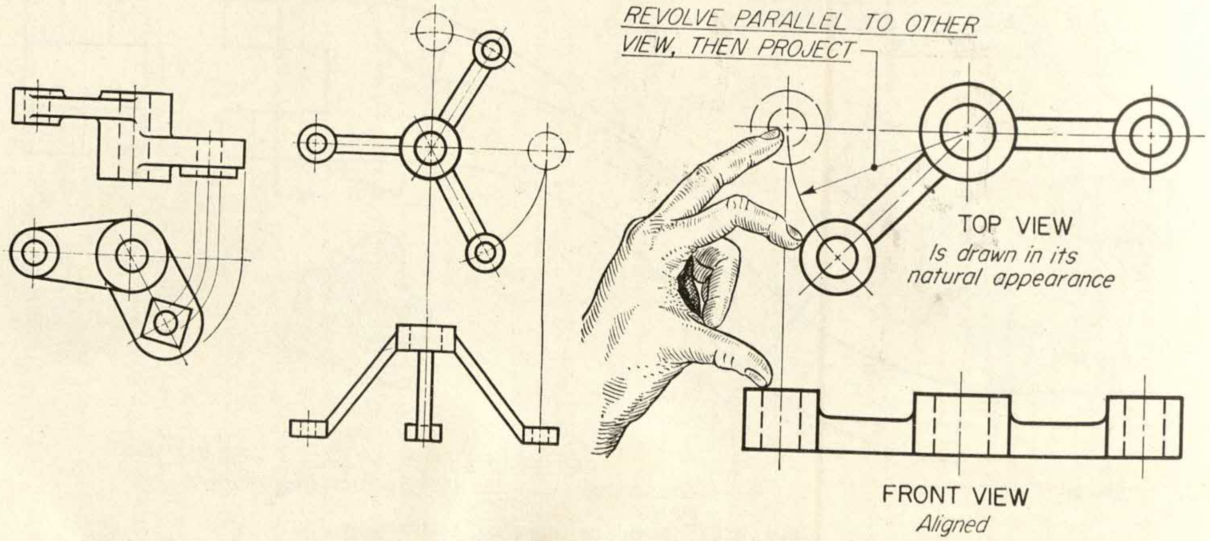

REVOLVE PARALLEL TO OTHER VIEW, THEN PROJECT
TOP VIEW
Is drawn in its natural appearance
FRONT VIEW
Aligned

Fig. 8-20. Alignment of parts.

readily comprehensible drawings. A number of the more common examples follow.

8-19. Aligned views. Parts that have features at an angle with each other, such as arms, lugs, and other like forms, may be shown straightened out, or aligned, in one view by imagining that the features at an angle are rotated into the plane of projection. Figure 8-20 shows three examples of aligned views. One of the views gives the natural appearance of each part, while in the adjacent views the arms are shown revolved into alignment to give understandable and symmetrical representations of the objects. These straightened-out views show the true shape of the features and their true distances from the centers to which they are related —something that could not be conveyed by strict orthographic representation.

8-20. Developed views. Pieces of thin material of various shapes are drawn in their true bent-shape contours in one view and shown stretched out to their over-all length in the adjacent or related view (see Fig. 8-21). In specifying over-all dimensions, extra metal must be allotted for bends. Exactly how much to allow is best determined from shop experience, although formulas are available. (See also Sec. 7-23.)

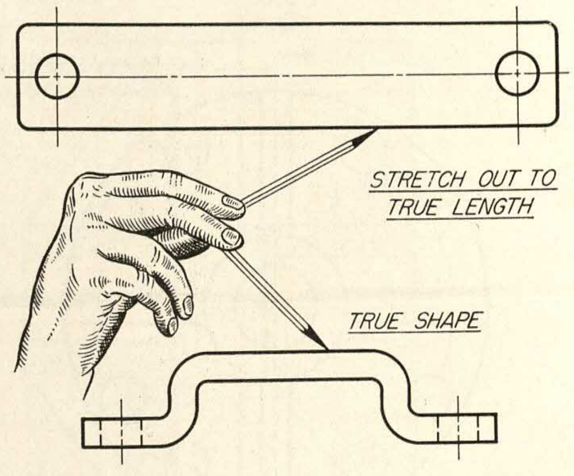
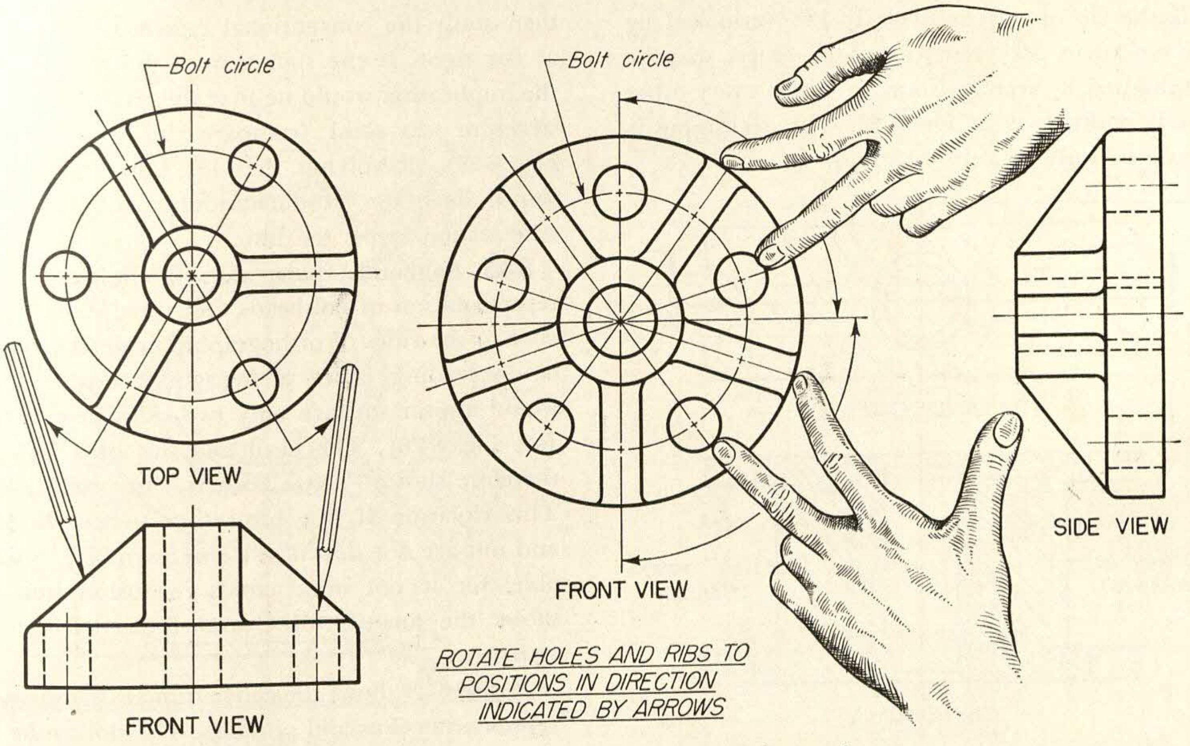


Fig. 8-21. Developed, or stretched-out, forms.

8-21. Revolution of ribs and holes. Ribs and holes that are arranged radially from a common center are rotated into the plane of projection in one view in order to convey a symmetrical appearance and to show the true distance of the features from the center of the part (see Fig. 8-22). The ribs and holes are shown in their true positions in the circular view, which also shows the plane of rotation.

8-22. Conventional practices in sectioning. Web- and riblike features of a part are not shown sectioned in section views. Although the cutting plane is shown passing lengthwise through the center of the ribs in the circular view, it should be



ROTATE HOLES AND RIBS TO POSITIONS IN DIRECTION INDICATED BY ARROWS

Fig. 8-22. Rotation of ribs and holes in ordinary views.

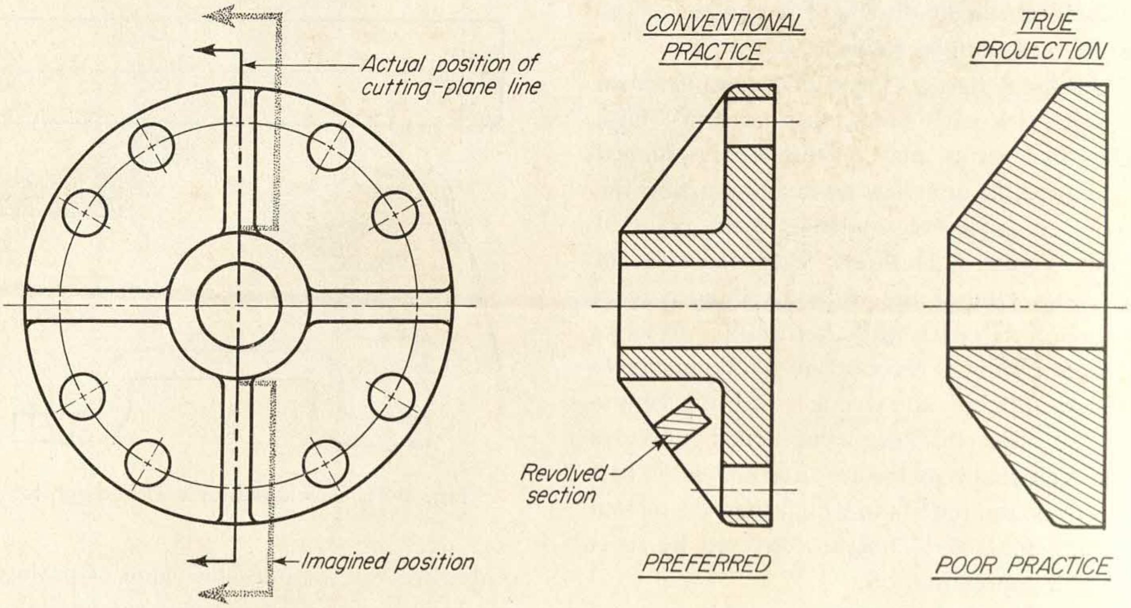


Fig. 8-23. Treatment of ribs and holes in sectioning.

imagined that the cutting plane is offset so as to pass just in front of the ribs (see Fig. 8-23). The section lining of the ribs is then omitted, and the ribs appear in outline form in the section view. This procedure avoids giving the misleading impression that the object is solid. In most cases, the inclusion of a revolved section as shown in the figure will show all that need be known about the shape of the ribs.

If the rib or web is likely to be overlooked by the workman, its presence on the object may be emphasized by section lining in which every other line is omitted, as in Fig. 8-24. This technique is employed only on rare occasions.

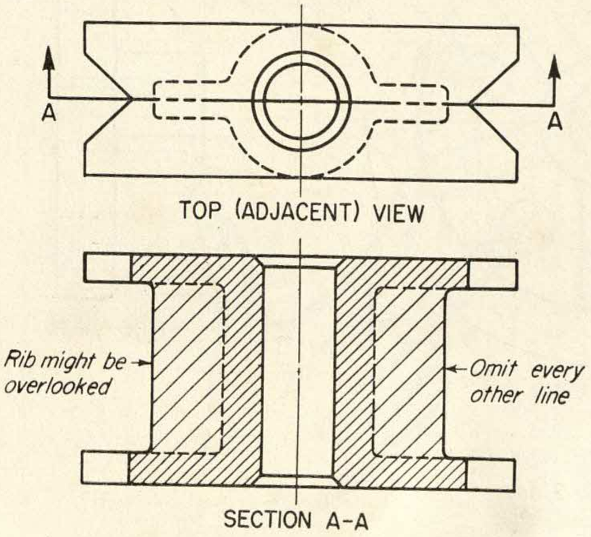


Fig. 8-24. Sectioning of ribs (rarely used).

Radially arranged ribs and holes located on the bolt circle are rotated into the plane of sectioning in the same manner as described in Sec. 8-21. The ribs are shown unsectioned, and the holes appear outlined in the section view (see Fig. 8-25). Arms, lugs, and other similar forms on parts such as those of Fig. 8-26 are treated in the same fashion.

Note the misleading true projection and sectioning of the wheel and its spokes in Fig. 8-27, and then study the conventional treatment illustrated at the right. If the spokes were shown sectioned, the implication would be that the rim's supporting structure was solid (compare this drawing with Fig. 8-23). Revolving the slot into the position shown facilitates its dimensioning and shows the true section across the hub.

8-23. Boltheads, nuts, slots, pinholes. In the representation of boltheads and nuts, strict adherence to the rules of orthographic projection would be misleading, since a hexagonal head or nut would appear to have only two sides in one view (see Fig. 8-28). The head and nut of a bolt are therefore shown "across corners," in profile views. This violation of true projection (when the head and nut are not shown in a slot assembly) is desirable, for it not only avoids confusion but also shows the amount of clearance needed for the fastener.

Figure 8-29 shows the conventional treatment for representing slots and pinholes. The slot in the cap screw is drawn at an angle of 45° in the circular

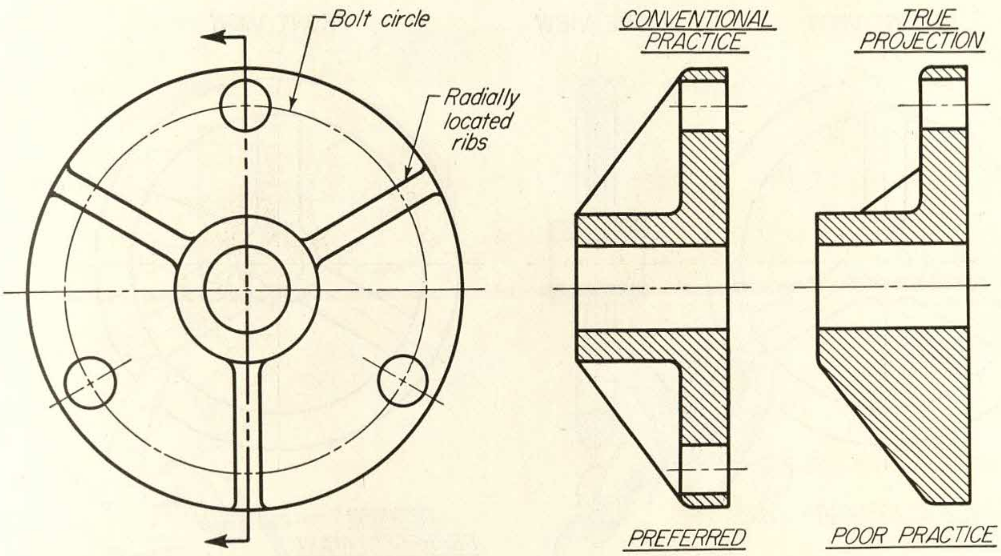


Fig. 8-25. Revolution of radially located ribs and holes on bolt circles.

view and in its true shape and position in the related profile view. The pinhole is shown in its true circular appearance in one view but at the attention-compelling angle of 45° in its related view.

8-24. Alternate positions. The method of showing an alternate position of a part, or the limiting position of a moving part, is shown in Fig. 8-30. The alternate or limiting-position lines of the object are drawn as long dashes finer and lighter than the lines of the object in the original position.

8-25. Unimportant intersections. Figure 8-31 shows the conventional manner of representing unimportant intersections of circular and rectangular forms. The extra work necessary for developing the true projected lines of intersection would serve no useful purpose, and thus this long procedure is ignored.

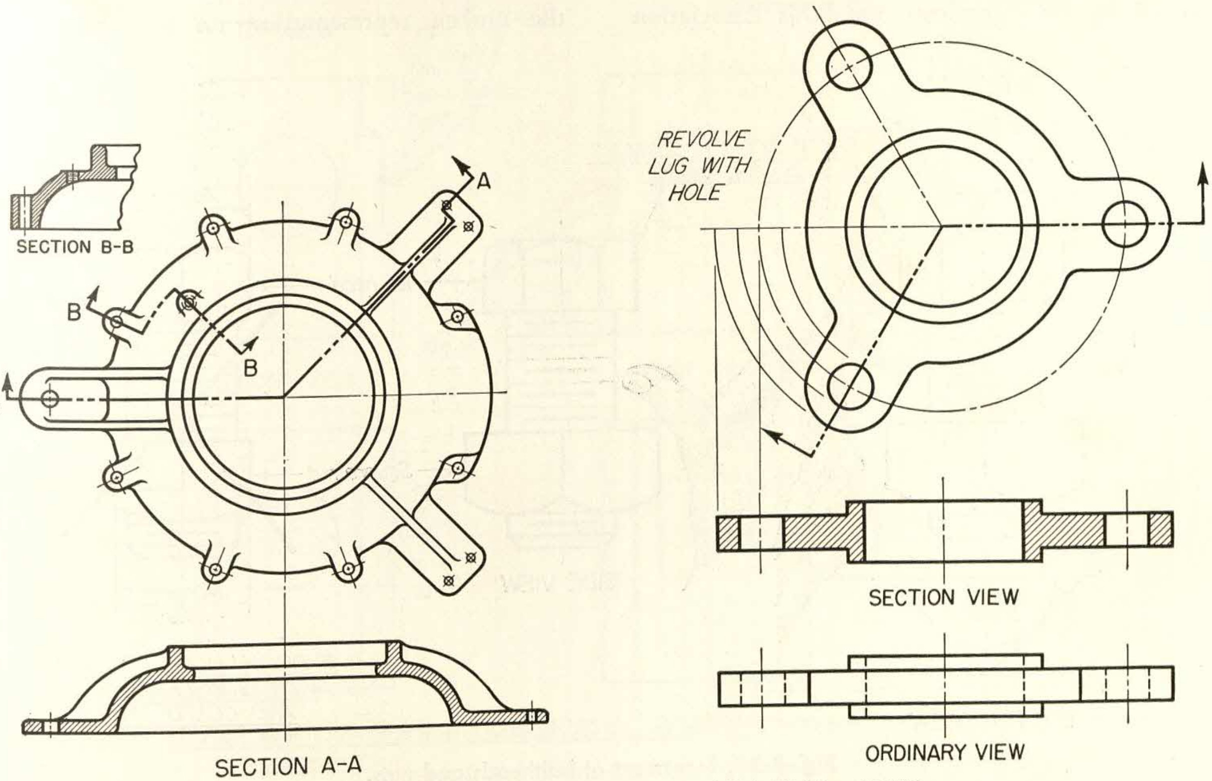


Fig. 8-26. Revolution of arms, lugs, etc. (ASA Z14.1—1946.)

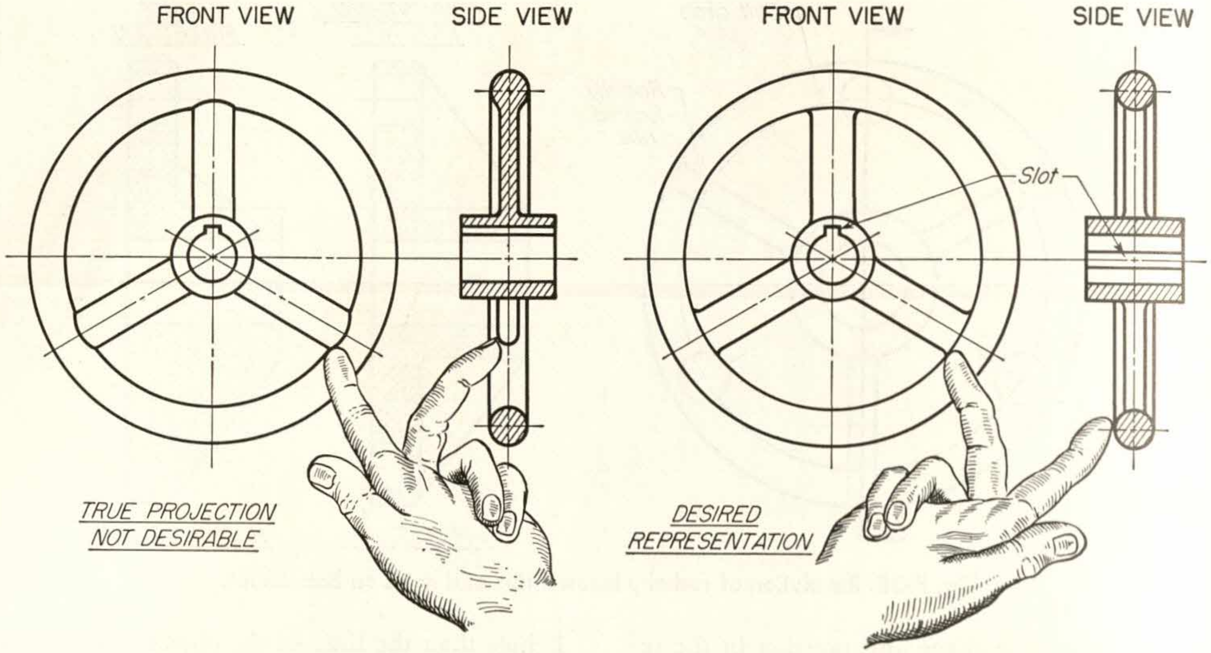


Fig. 8-27. True and conventional representation of a wheel and its spokes.

8-26. Conventional breaks. When unusually long, simply constructed features, such as bars, rods, shafts, tubes, and arms, are to be drawn, the entire length need not be shown on the sheet. The form may be broken at a convenient position and a cross section shown at that point, or a conventional break may be used such as those recommended by the American Standards Association (see Fig. 8-32). Conventional breaks may be drawn with a compass or irregular curve or freehand on either detail or assembly drawings (see the right-hand portion of Fig. 8-32). A part having repeated similar features may be represented by the completion of several of its profiles and the use of ditto lines as shown in Fig. 8-33. Although the broken representation on the sheet is not

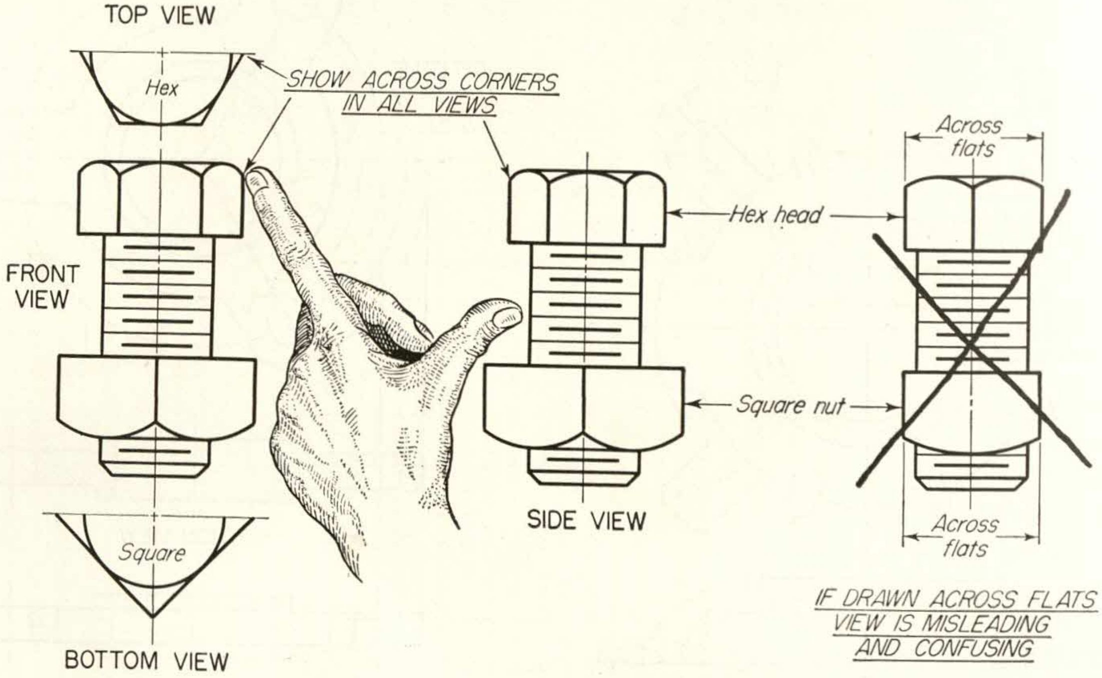


Fig. 8-28. Treatment of boltheads and nuts.

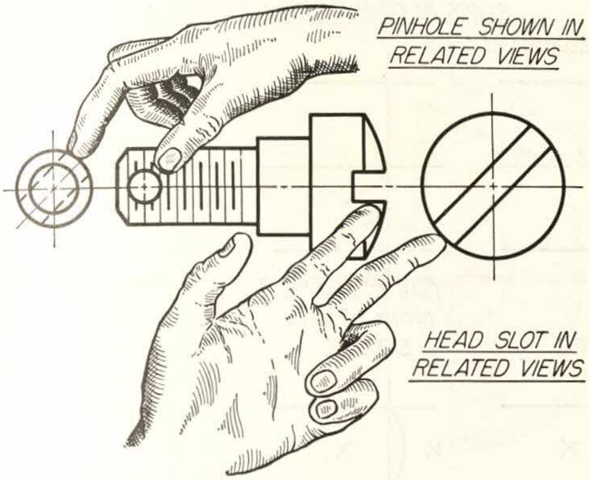


Fig. 8-29. Treatment of head slots and pin holes.

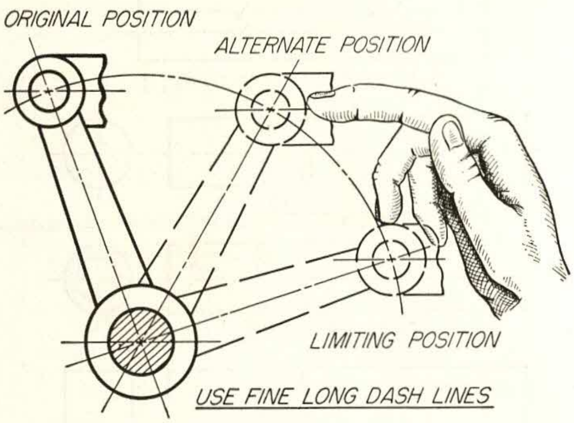


Fig. 8-30. Alternate positions.

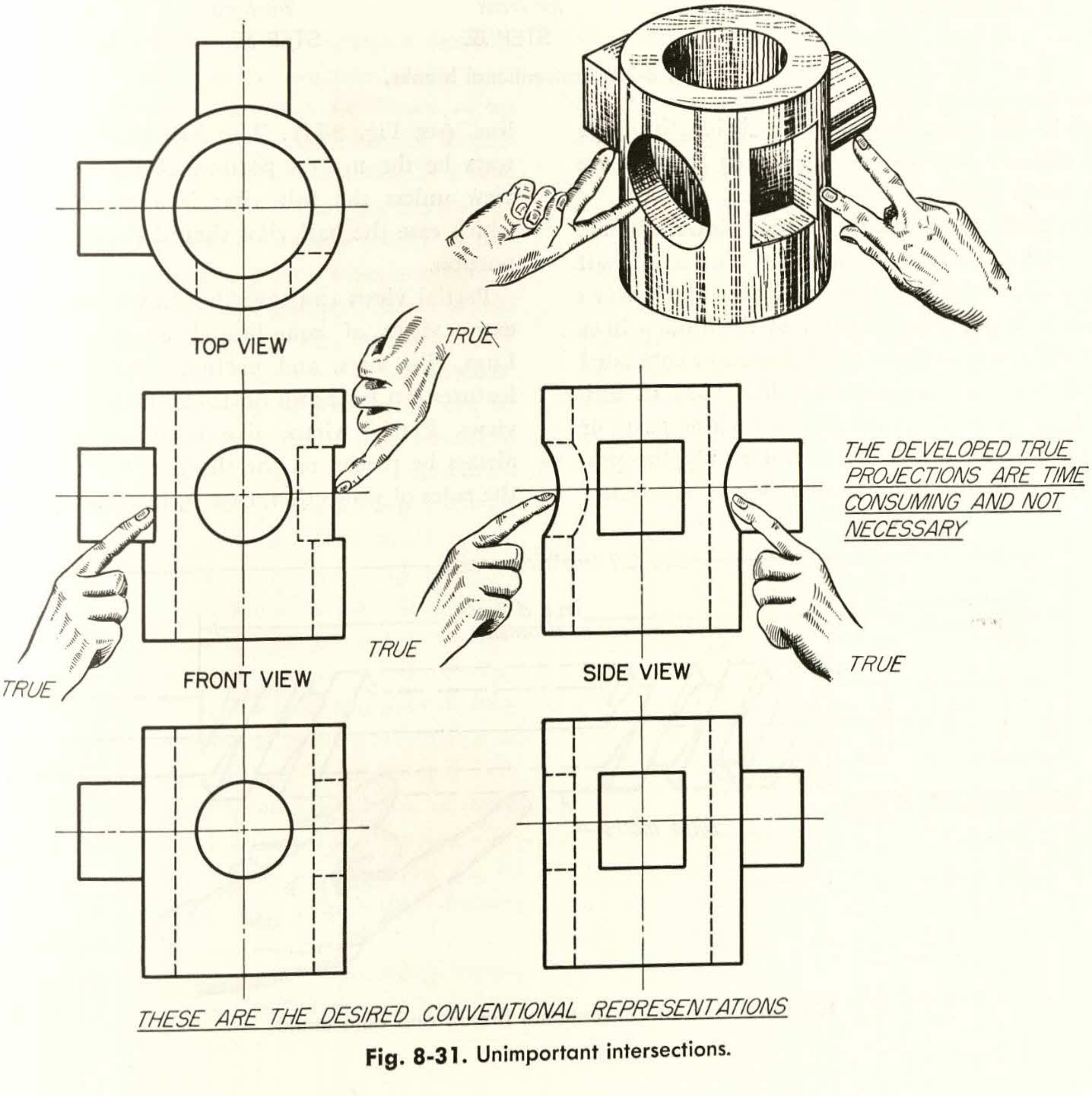

TOP VIEW
TRUE
THE DEVELOPED TRUE PROJECTIONS ARE TIME CONSUMING AND NOT NECESSARY
TRUE
TRUE
FRONT VIEW
SIDE VIEW
TRUE
THESE ARE THE DESIRED CONVENTIONAL REPRESENTATIONS

Fig. 8-31. Unimportant intersections.

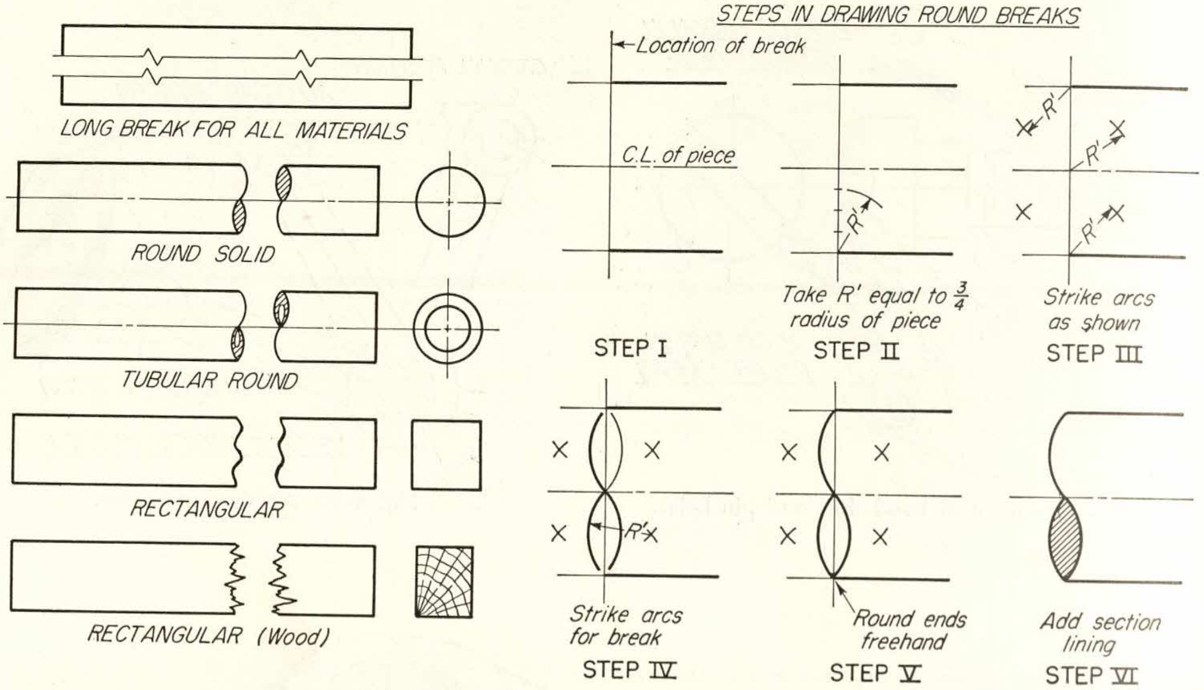


Fig. 8-32. Conventional breaks.

drawn to full scale, the true over-all length of the piece and the true distances between features are given when the piece is dimensioned.

8-27. Half views and partial views. Time, labor, and space may be saved by the use of half views and partial views. In addition, these views are often clearer because many of the hidden lines that would ordinarily be needed to show concealed features may be eliminated. A half view of uniform circular or elliptical pieces, such as gears or pulleys, may be drawn by showing only the portion of the object lying to one side of the center line (see Fig. 8-34). The half drawn should always be the nearest portion of the adjacent full view unless the full view is a section view, in which case the half view should show the farthest portion.

Partial views can save the drawing of complete extra views of complicated or irregular parts. Lugs, ribs, bars, and portions containing special features can be shown quite satisfactorily in partial views. Partial views, like complete views, must always be placed on the sheet in accordance with the rules of projection, that is, in direct projection

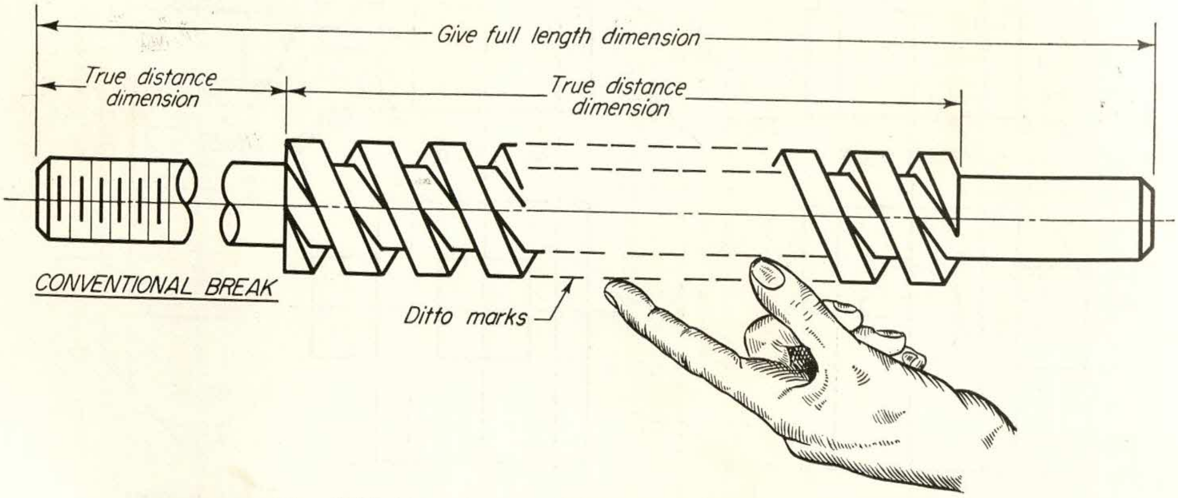


Fig. 8-33. Use of conventional breaks and ditto marks.

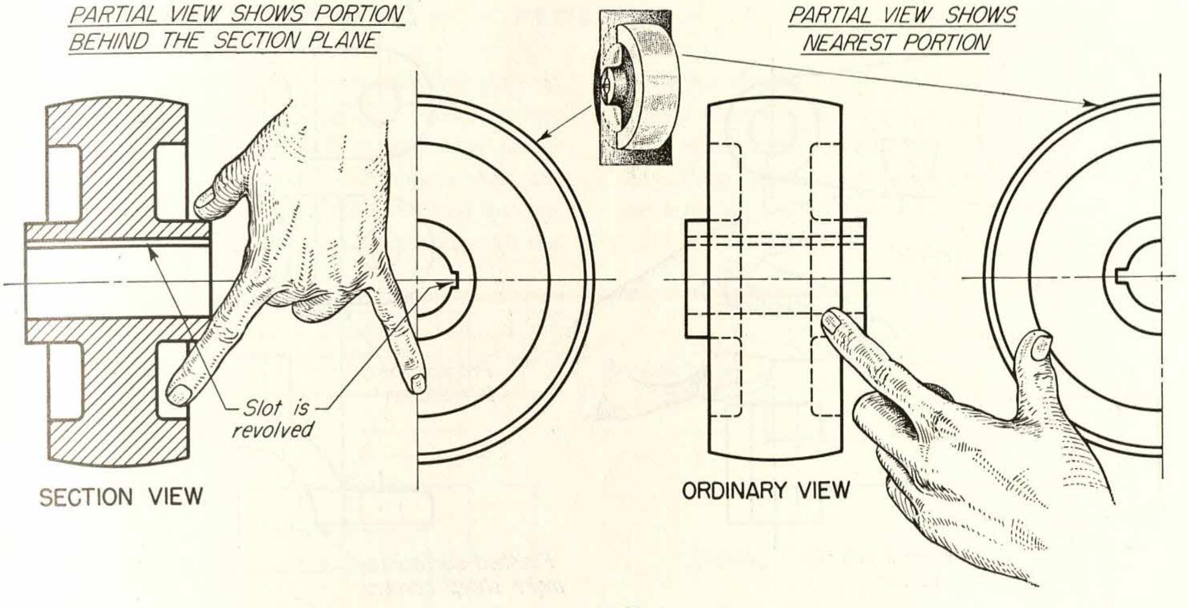

PARTIAL VIEW SHOWS PORTION BEHIND THE SECTION PLANE
PARTIAL VIEW SHOWS NEAREST PORTION
Slot is revolved
SECTION VIEW
ORDINARY VIEW

Fig. 8-34. Half views.

from the views to which they are adjacent (see Fig. 8-35). Partial views may be portions of the top, side, front, etc., views and may be drawn to an enlarged scale to facilitate visualization or dimensioning, in which case the scale is added as a note near the view. Note that break lines are used where necessary to indicate the incomplete nature of partial views. When a half or partial view is shown, at least one complete view of the object should always appear on the same sheet. (See Fig. 7-9 also.)

8-28. Fillets, rounds, runouts. The intersections formed by surfaces of objects often can be shown more clearly if a conventional treatment is adopted. The intersection of two unfinished surfaces at an inside corner of a casting is always rounded for greater strength. This small curved intersection is called a "fillet" (see Fig. 8-36). A fillet is formed by the intentional rounding of the edges of the pattern by the patternmaker. Outside corners of castings are rounded in the cooling process and improve appearance and ease of handling. The rounded external corners are known as "rounds." In drawing corners of unfinished castings, fillets and rounds should be shown. A sharp edge or corner should be drawn when one surface is to be machined and the other left in its original state or when both intersecting surfaces are to be machined.

Supporting, bracing, or strengthening forms, such as ribs and webs, will often run smoothly into other surfaces or features and terminate in curves called "runouts," which are conventional representations of filleted intersections where the change in direction is so gradual that theoretically no line should be drawn.

If iron is used in casting, the fillets and rounds are generally about $\frac{1}{8}$ in. in radius. Use of the white metals (aluminum, zinc, etc.) results in $\frac{1}{16}$-in. fillets or rounds. The draftsman should indicate the size of all undimensioned fillets and rounds by a note on the drawing sheet, thus: "All fillets and rounds $\frac{1}{8}''$," or "All fillets and rounds $\frac{1}{16}''$ unless otherwise specified." Such a note should

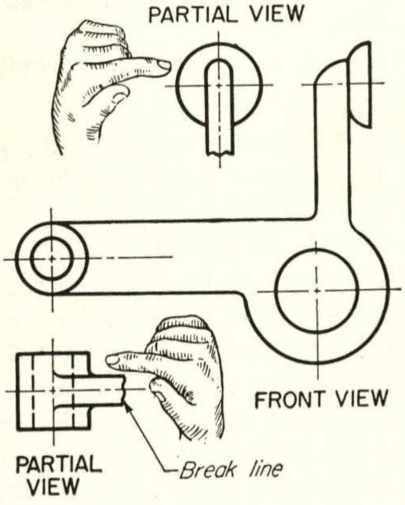


Fig. 8-35. Partial views.

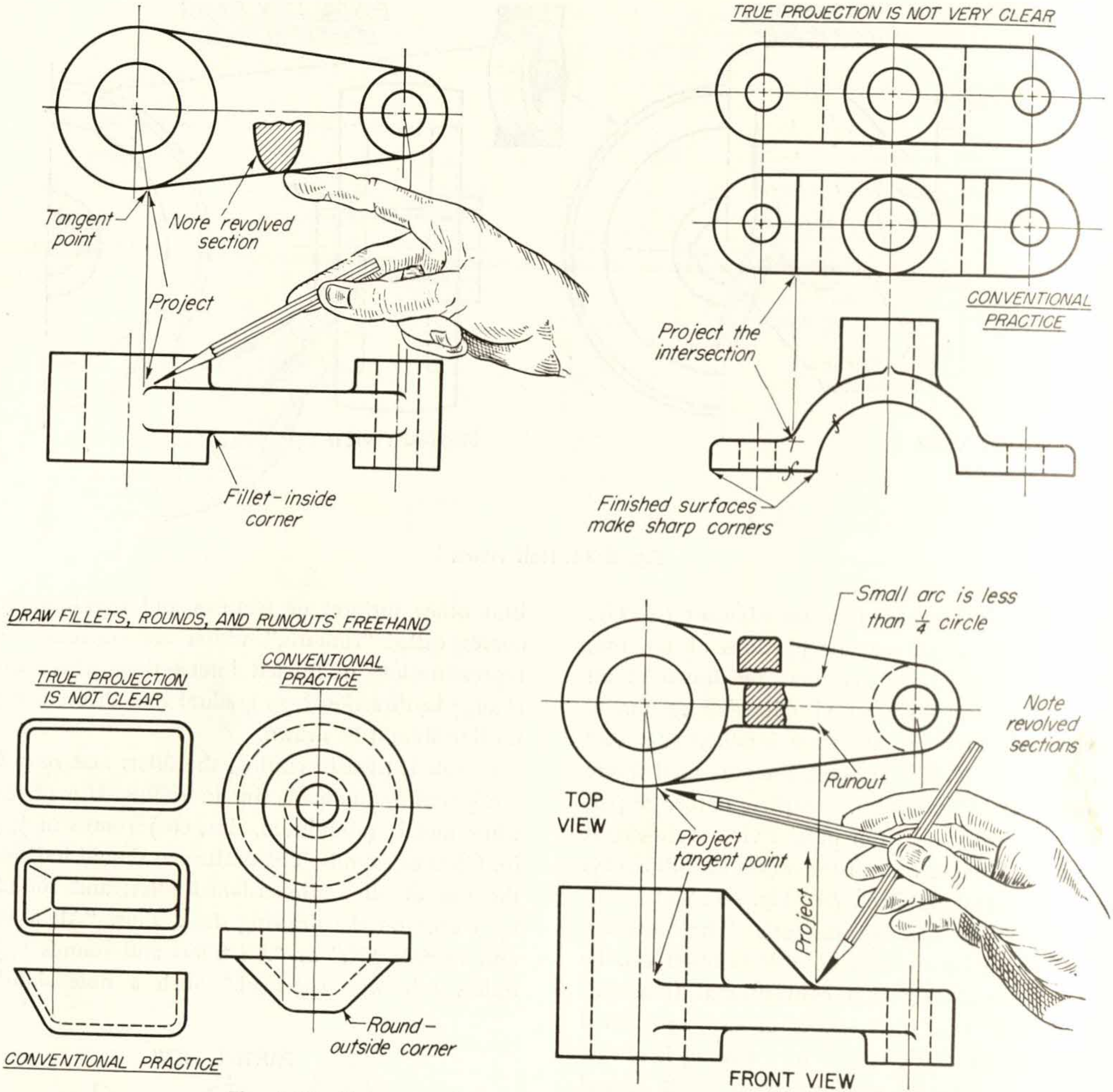


Fig. 8-36. Conventional treatment of fillets, rounds, and runouts.

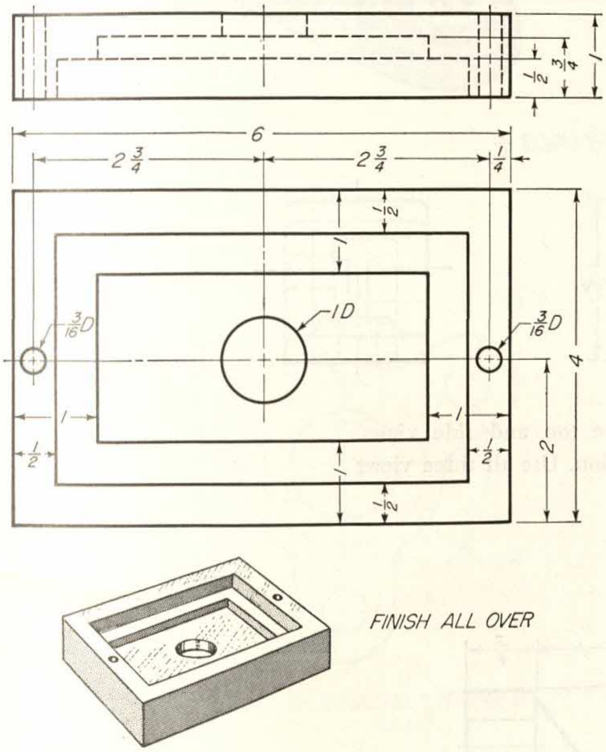
be placed near enough to one of the principal views so as to appear as part of the regular dimensioning of the object.

The conventional treatment used in drawing some of the types of fillets and rounds encountered in practice is shown in Fig. 8-36. Arcs are usually drawn freehand; however, some draftsmen prefer to use a compass or a french curve. In drawing fillets and runouts, the tangent point should be projected to the adjacent view, where the representation is then shown by an arc of a radius equal to the fillet or runout. The curved segment of the runout should be noticeably less than a quarter circle. The extreme end of the arc is in direct projection with the tangent point in the other view, and the cross section of the material (web, rib, etc.) determines the direction in which the arcs turn.

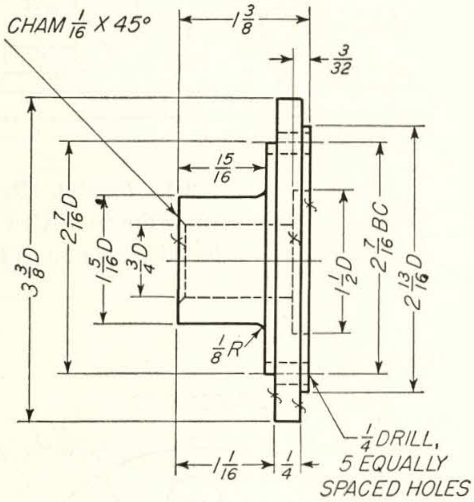
On an outside surface, the theoretical intersection forming a round is projected from the circular view to the adjacent view, where it is represented by the required solid or hidden lines. The true smooth projection of the round (or fillet) is ignored in order to offer a more comprehensible representation on the drawing from which the shopman will work.

PROBLEMS

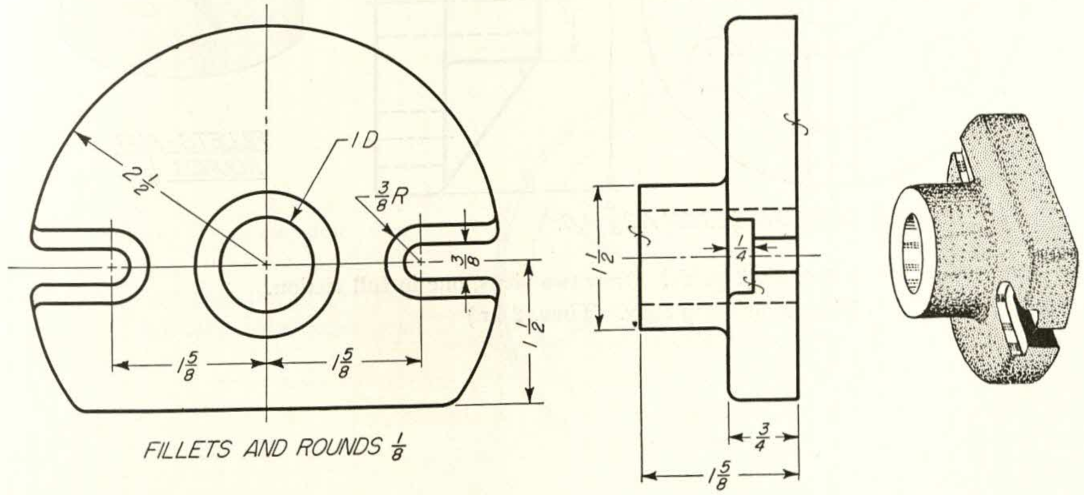
The following problems have been especially selected to give the student practice in applying his knowledge of conventional treatments as well as sectioning procedure. Most of the problems deal with objects that contain special features such as holes, ribs, and lugs that are to be treated conventionally in the related views. All the drawings should be properly and completely dimensioned according to the principles set forth in Chap. 7. The section views should be dimensioned, when necessary, along with the ordinary views. The drawings should be made on 8½- by 11-in. sheets.



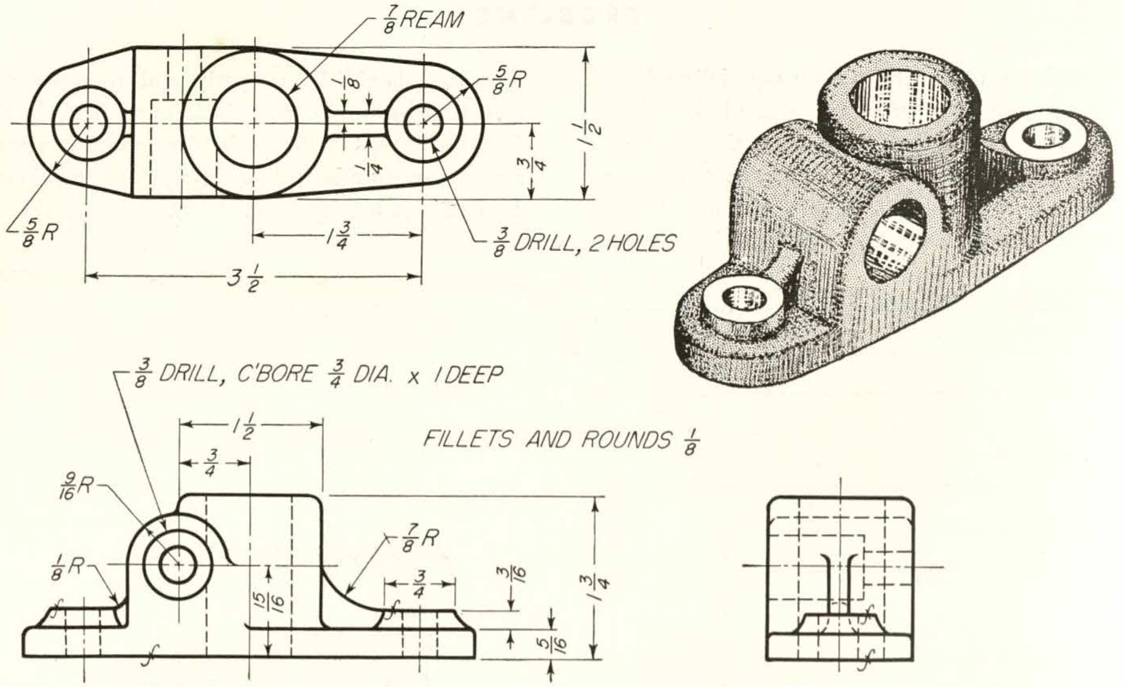
8-1. *Cover plate.* Reproduce the front view. Draw the top view as a full section. Dimension completely. (Time. 1½ hr.)



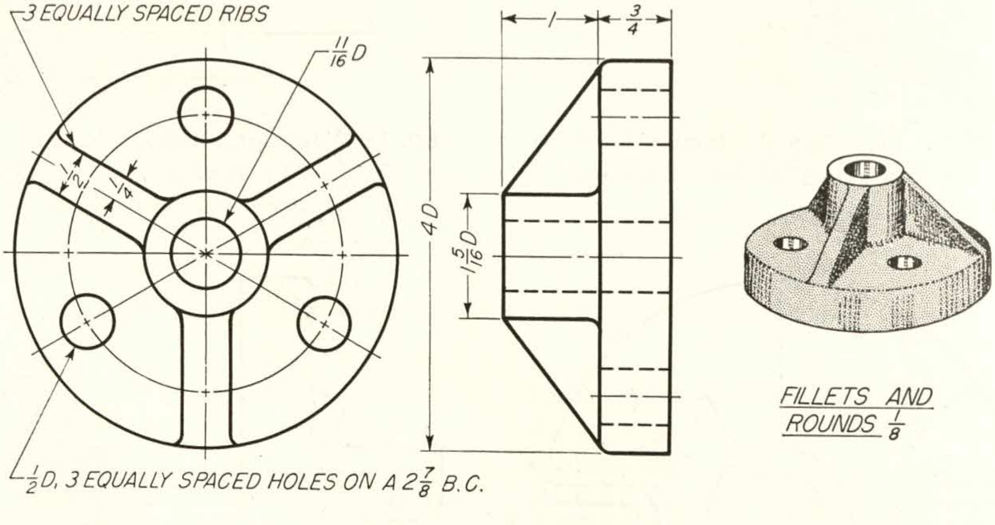
8-2. *Shaft support.* Redraw the given view as the front view in full section. Show the side view. Dimension properly and completely. (Time. 3 hr.)



8-3. *Jack base.* Redraw the front and side views so that the side view will be a full section. The cutting plane should pass through both slots and the center hole of the front view. Dimension completely. (Time. 2 hr.)

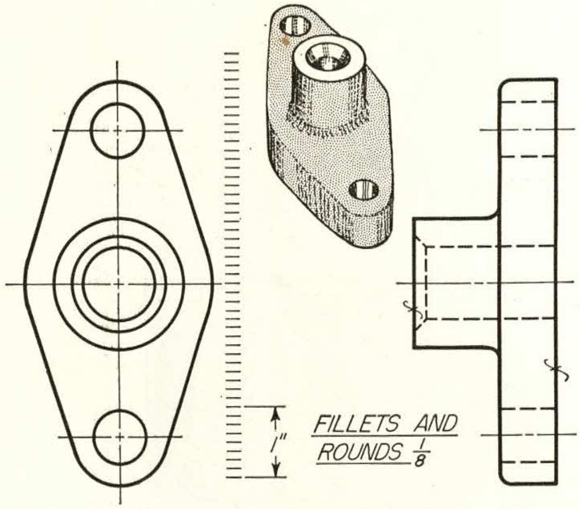


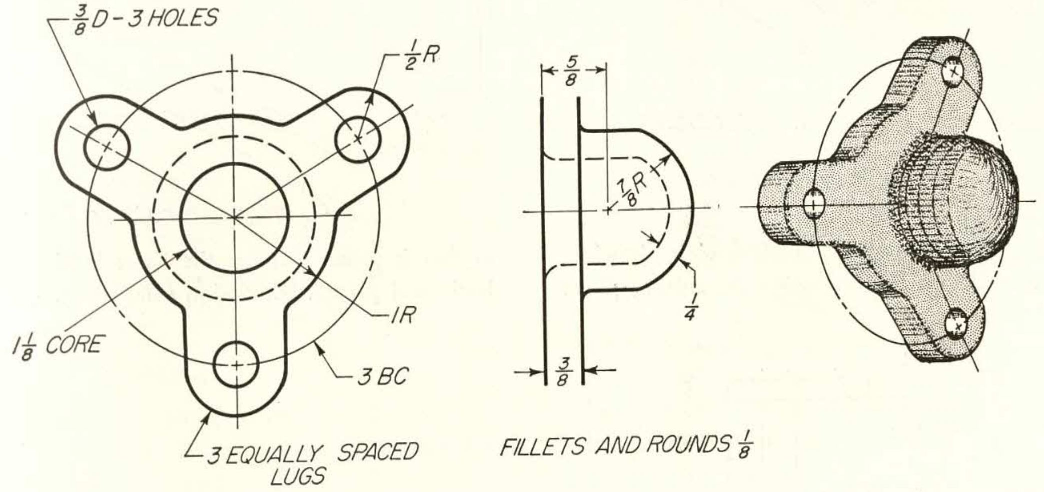
8-4. *Bracket.* Reproduce the top and side views. Draw the front view in full section. Use all three views for dimensioning. (Time. 4 hr.)



8-5. *Shaft guide.* Draw two views, one in full section. Dimension completely. (Time. 2 hr.)

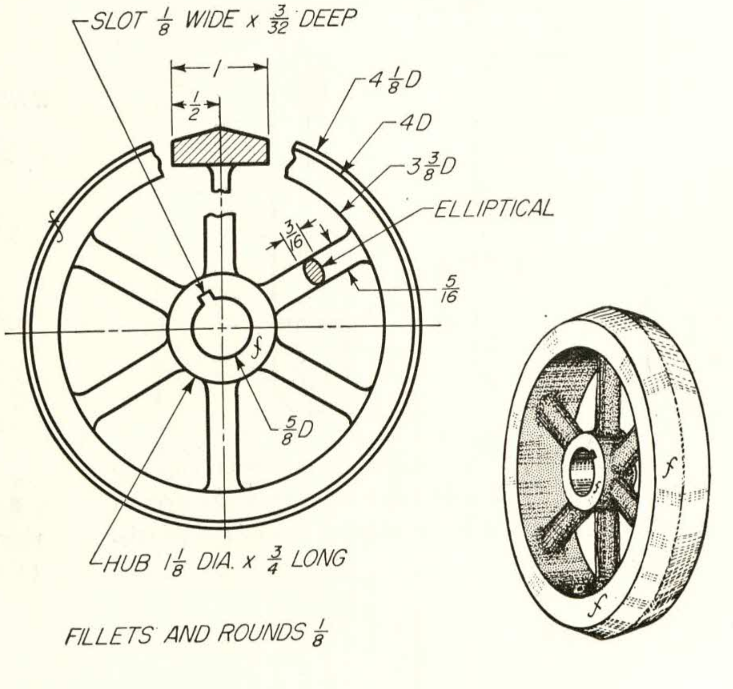
8-6. *Gland.* Reproduce the front view. Complete the side view as a full section. Dimension completely. (Time. 2 hr.)

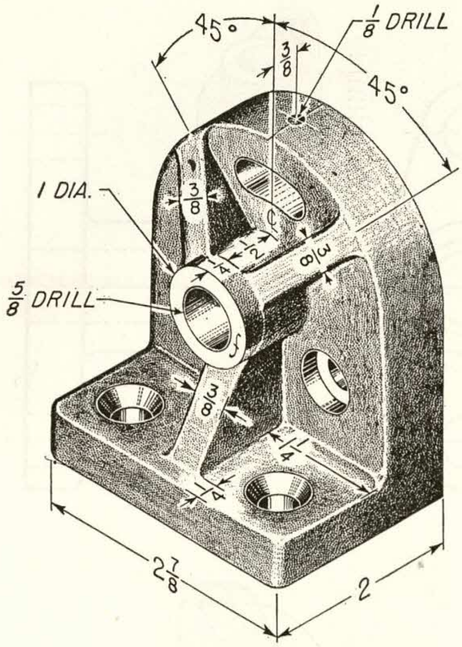




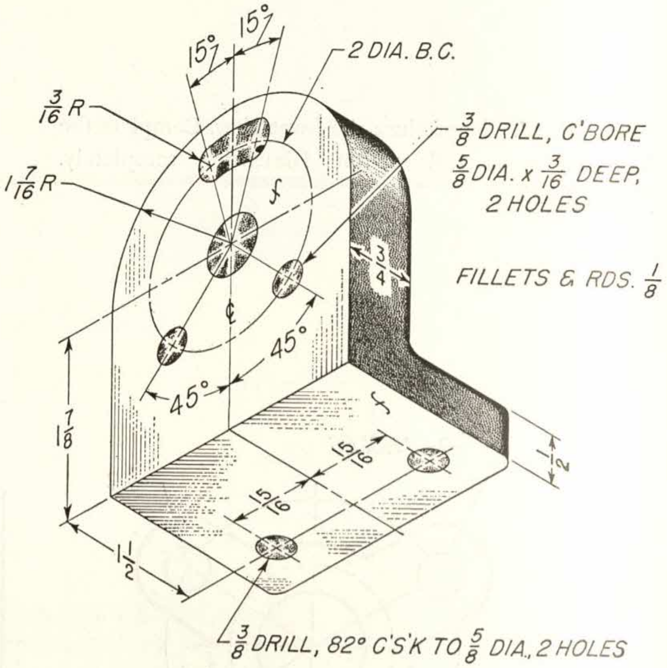
8-7. *Cover plate.* Redraw the front view. Complete the side view as a full section, showing the proper treatment of the lugs. Dimension completely. (Time. 2½ hr.)

8-8. *Pulley.* Redraw the front view, omitting the revolved section of the rim. Add a side view in full section, showing the proper location of the slot in this view. Dimension completely. (Time. 2½ hr.)

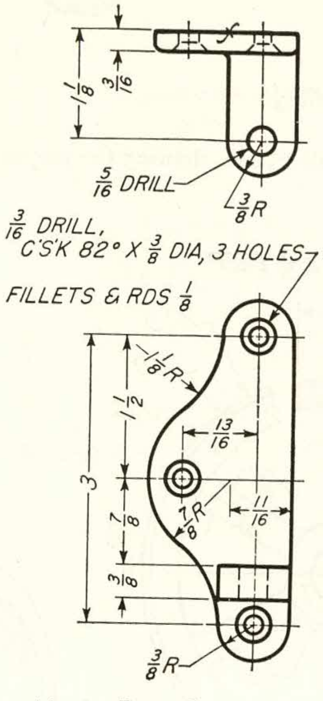




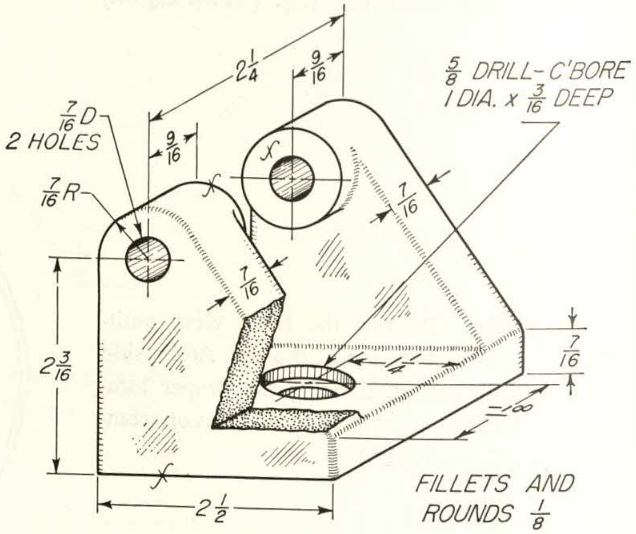
REFER TO BOTH VIEWS FOR DIMENSIONS


15°
15°
2 DIA. B.C.
3/16 R
1 7/16 R
3/8 DRILL, C'BORE 5/8 DIA. x 3/16 DEEP, 2 HOLES
3/4
FILLETS & RDS. 1/8
℄
45°
45°
1 7/8
15/16
15/16
1/2
1 1/2
3/8 DRILL, 82° C'S'K TO 5/8 DIA., 2 HOLES

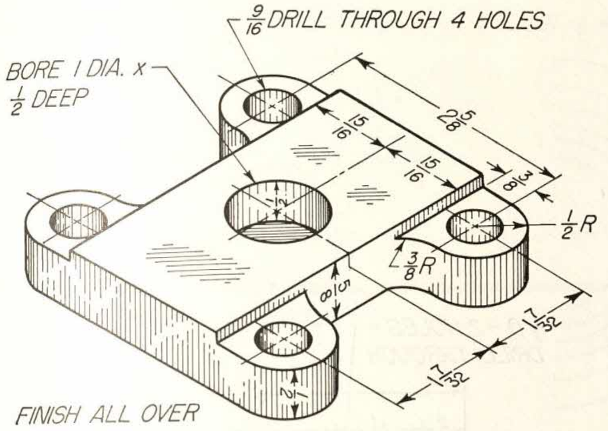
8-9. *Bearing bracket.* Make a three-view drawing. Show one view in full section. Offset the cutting plane so that it passes through the holes in the vertical and horizontal planes. Dimension completely. (Time. 4 hr.)



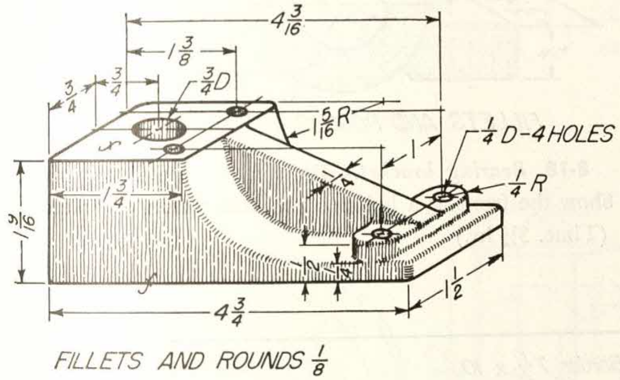
8-10. *Shaft support.* Reproduce the front and top views. Add a side view in full section by employing an offset cutting plane. Dimension properly and completely. (Time. 2½ hr.)



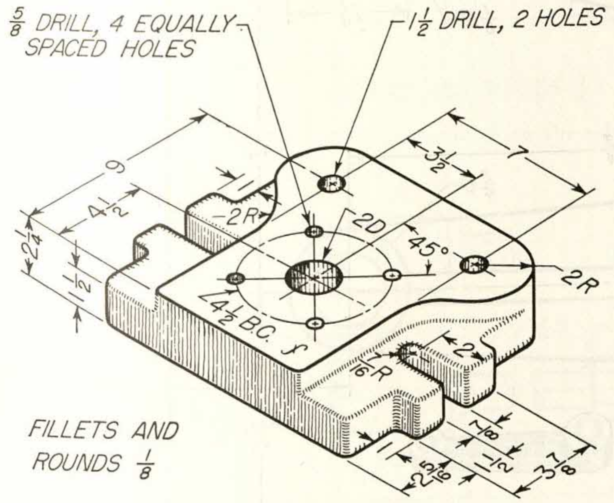
8-11. *Caster frame.* Make three views. Show one view as a full offset section. Dimension completely. (Time. 2½ hr.)



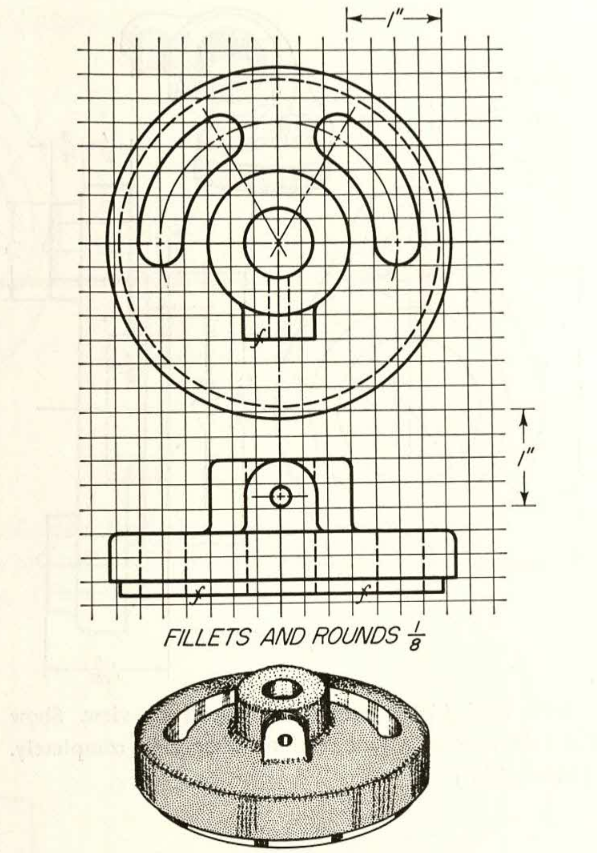
8-12. *Face plate.* Draw two views. Make one a full offset section. Dimension completely. (Time. 2½ hr.)



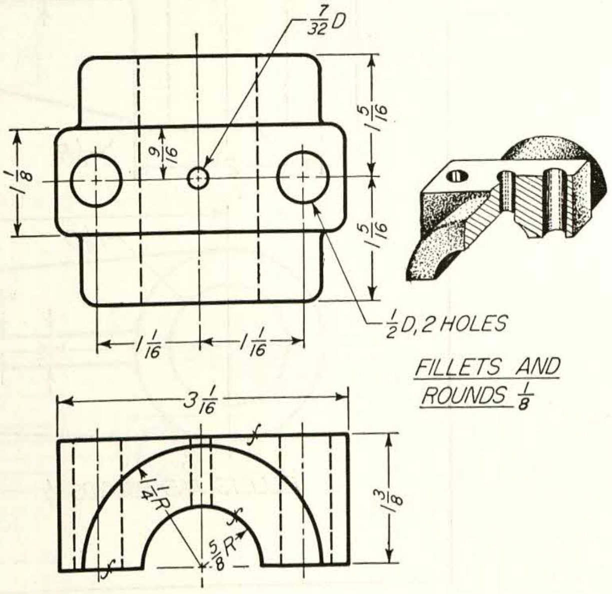
8-13. *Float bracket.* Draw a front and top view. Make the front view a suitable full offset section. Dimension completely. (Time. 3 hr.)



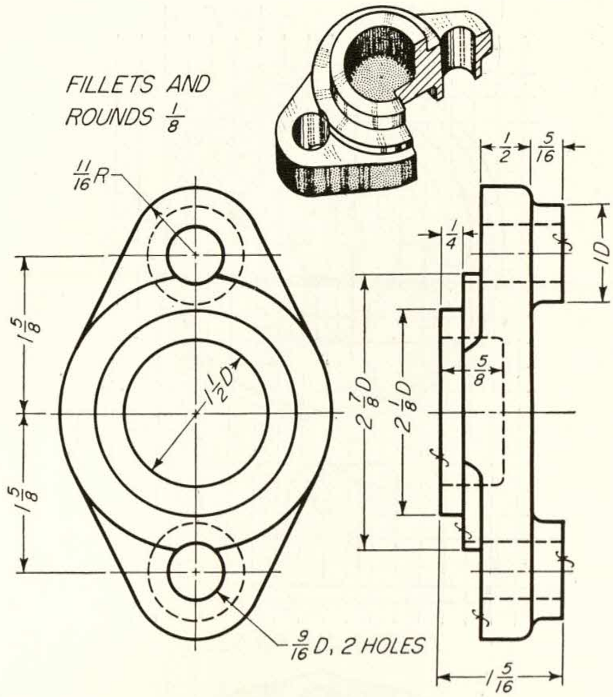
8-15. *Die shoe.* This offers varied treatment as a sectioning problem. The choice is left to the student. Draw three views, and dimension completely. Make object half size on an 8½- by 11-in. sheet. (Time. 4 hr.)



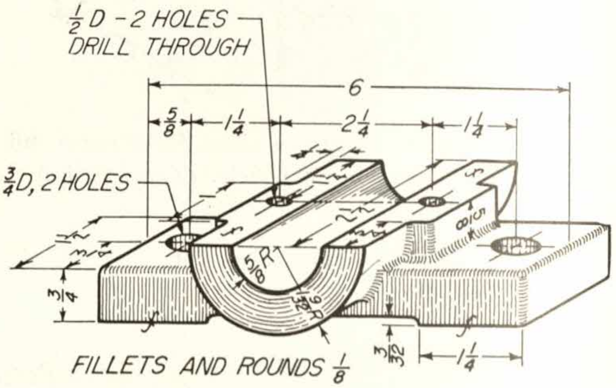
8-14. *Cover plate.* Reproduce the top view, showing a broken-out section at the oil hole. Make a full-section front view. Each frame is a ¼-in. square. Dimension completely. (Time. 3 hr.)



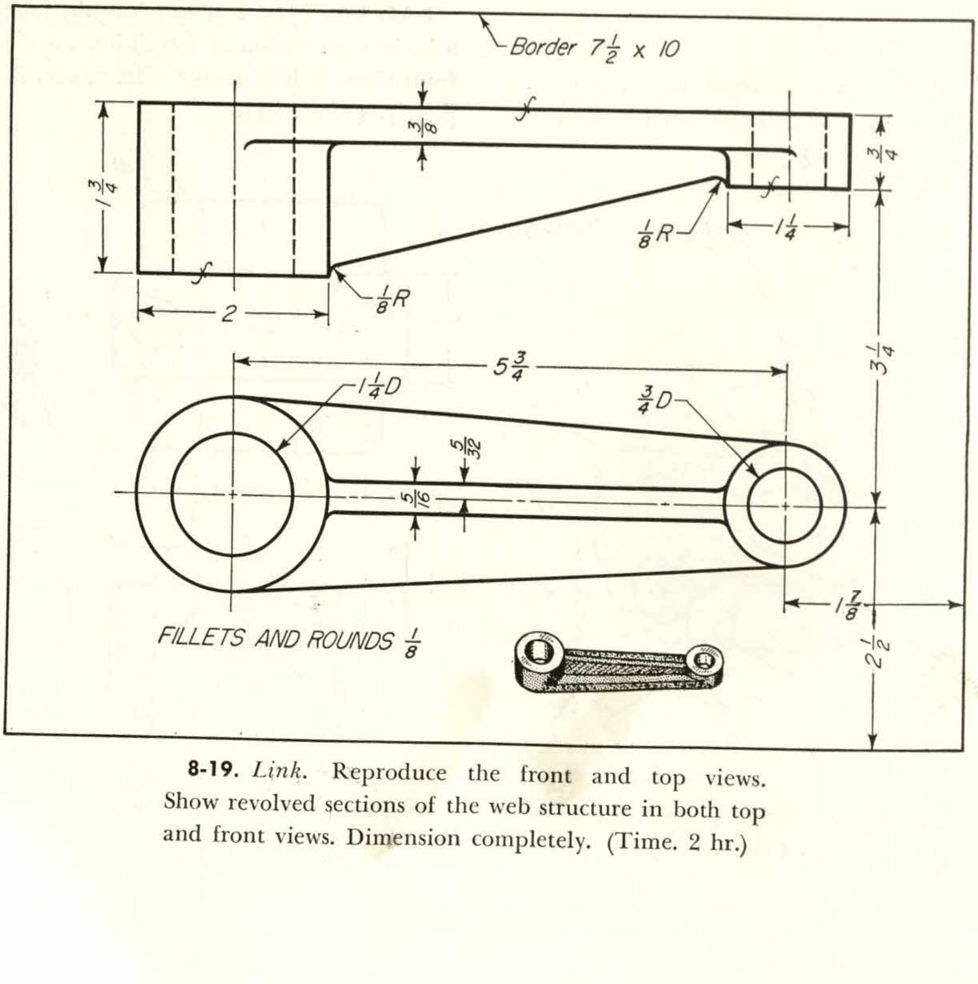
8-16. *Bearing-bracket cap.* Reproduce the top view. Make the front a half-section view. Dimension completely. (Time. 2½ hr.)



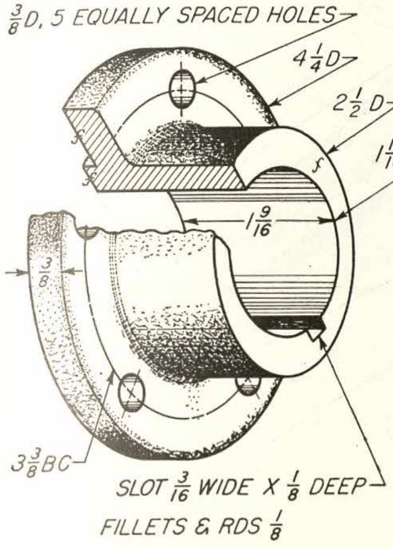
8-17. *End plate.* Reproduce the front view. Show the side view as a half section. Dimension completely. (Time. 3 hr.)



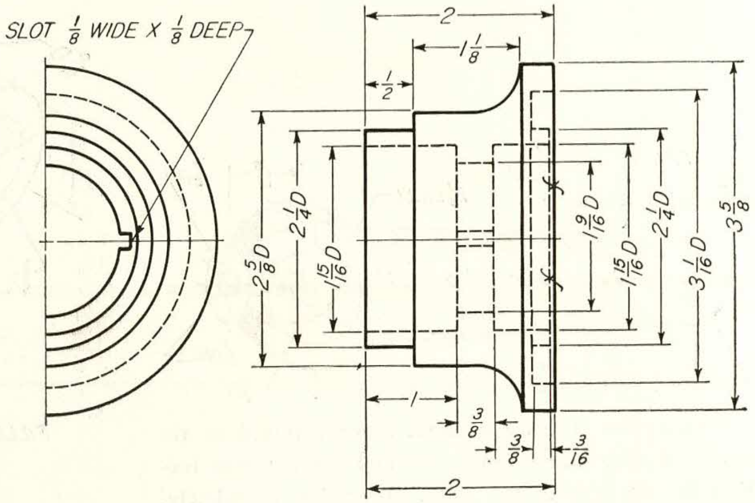
8-18. *Bearing bracket.* Draw a front and top view. Show the front as a half section. Dimension completely. (Time. 3½ hr.)



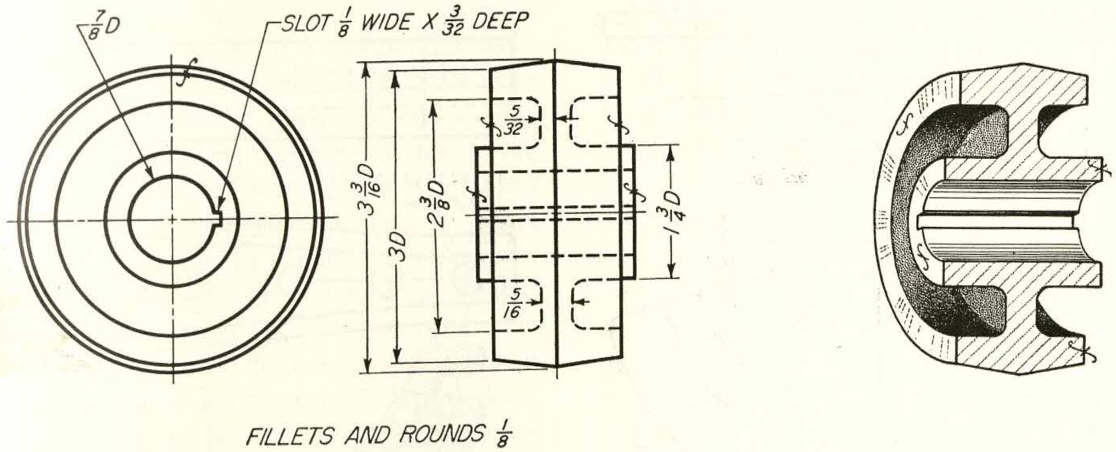
8-19. *Link.* Reproduce the front and top views. Show revolved sections of the web structure in both top and front views. Dimension completely. (Time. 2 hr.)



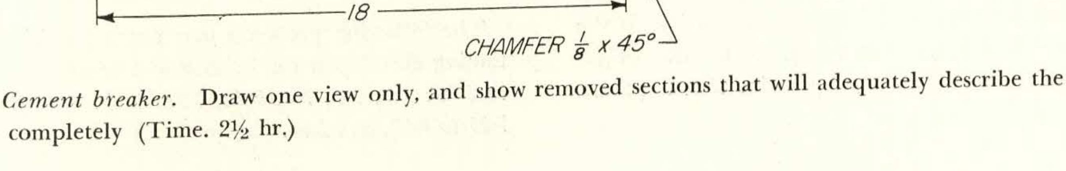
8-20. *Cover.* Make a two-view drawing, showing one in half section. Dimension completely. (Time. 2 hr.)



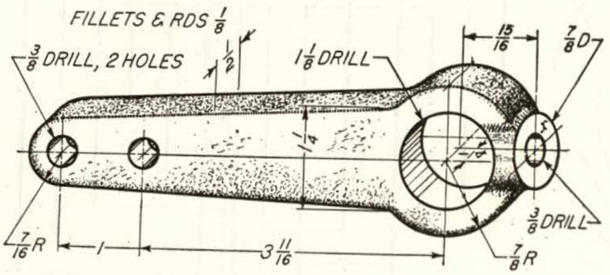
8-21. *Gland.* Reproduce the given views, showing the side as a half section. Include the dimensions in your drawing. (Time. 3 hr.)



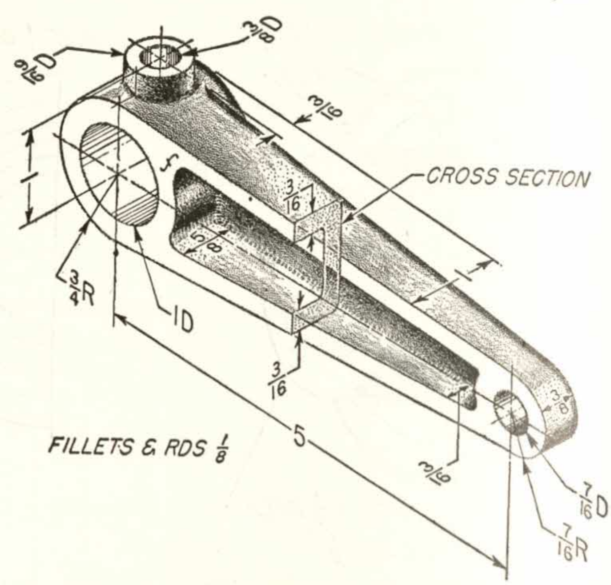
8-22. *Pulley.* Reproduce the front view. Show the side as a half section. Dimension completely. (Time. 2 hr.)



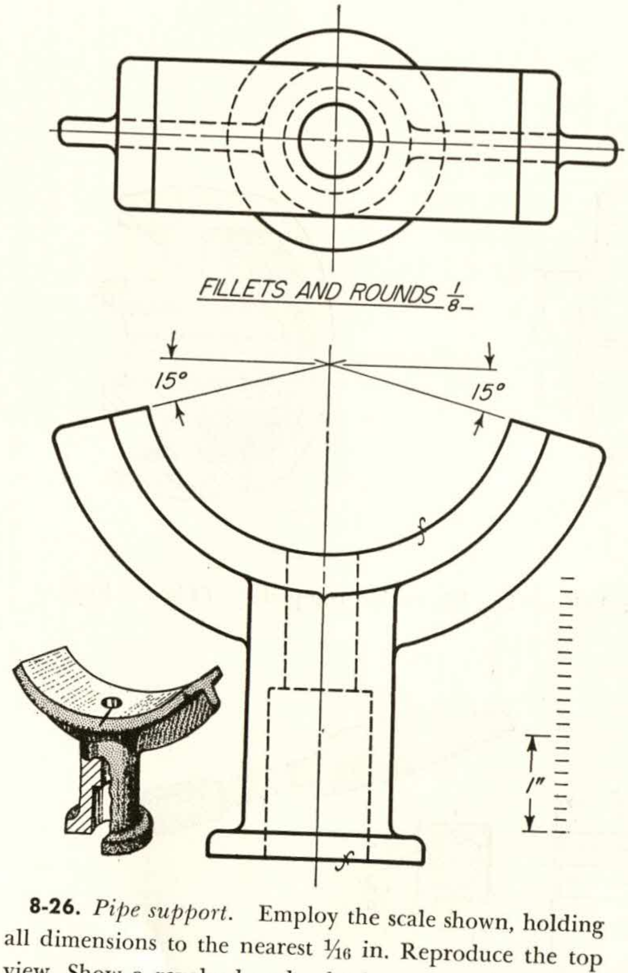
8-23. *Cement breaker.* Draw one view only, and show removed sections that will adequately describe the piece. Dimension completely (Time. 2½ hr.)



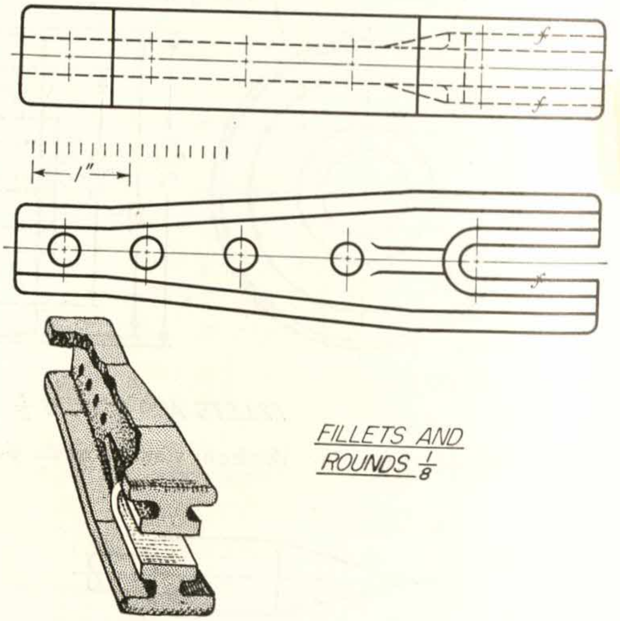
8-24. *Lever.* Draw one view. Show revolved or removed sections where applicable and a broken-out section for the hole at the right. Dimension completely. (Time. 1½ hr.)



8-25. *Lever.* Make a two-view drawing. Employ sectioning practices applicable to the part. Dimension completely. (Time. 3 hr.)



8-26. *Pipe support.* Employ the scale shown, holding all dimensions to the nearest 1/16 in. Reproduce the top view. Show a revolved and a broken-out section in the front view. Dimension completely. Make the object three-quarter size on an 8½- by 11-in. sheet. (Time. 2½ hr.)



8-27. *Cable guide.* Employ the scale shown, holding all dimensions to the nearest 1/16 in. Draw the front view only. Make removed sections that will adequately describe the piece. Dimension completely. (Time. 2½ hr.)

The following problems may also be assigned as sectioning exercises if the instructor desires: *Problems 3-20 to 3-23; 7-3, 7-4, 7-6, 7-12, 7-16, 7-17, 7-19, 7-23, 7-33, 7-35 to 7-37, and 7-44.*

Chapter 9

PRIMARY AUXILIARY VIEWS

One of the basic rules of dimensioning states that a line should be dimensioned only in the view where it is seen in its true length and that a plane with its details should be dimensioned only in the view where it is seen in its true shape. Since every object that is drawn is bounded by lines and planes and some of these may lie inclined or oblique to the principal planes of projection, it is obvious that the draftsman must be able to select and draw the view that will show the true length of a line or the true shape of a surface so that he may include on his working drawing all notes and dimensions necessary for producing the part.

A simple object may be rectangular in shape, and its lines and surfaces can be shown in their true dimensions by making use of a combination of two or more of the principal views. When an object contains an inclined surface, however, the true shape of the surface can be shown only by an auxiliary view that is drawn on a plane of projection that is placed parallel to the inclined surface.

9-1. Primary auxiliary views. Any view that is not projected to one of the principal planes may be classified as an auxiliary view. A *primary auxiliary view* is a view projected to a plane perpendicular to one of the three principal planes—front, top, or side—and inclined to the other two. Such a plane is shown in Fig. 9-1 (the auxiliary plane is inclined to the top and side views and perpendicular to the front). Note that the true shape of the inclined surface can be seen only on a plane lying parallel to the inclined surface. The method of projecting the image of an object to an auxiliary plane is identical to that employed for projecting an image to one of the principal planes; the projectors are parallel, and the observer is stationed an infinite distance away.

9-2. True size and shape of a plane. If a surface of an object is inclined to any one of the principal planes it will not show in its true shape in any of the principal views (see planes 1-2-3-4 and 2-5-6-7 in Fig. 9-2*a*). The true-shape projection of a plane surface is seen on a plane of projection passed parallel to that surface (see Fig. 9-2*b*).

9-3. Types of primary auxiliary views. The three types of primary auxiliaries are shown in Fig. 9-3. The auxiliary elevation (*a*) is inclined to the front and side views and is perpendicular to the top. The inclined auxiliary at (*b*) is at an angle to the top and side views and is perpendicular to the front. At (*c*), the auxiliary is inclined to the front and top views and is perpendicular to the side. Any number of auxiliary planes may be

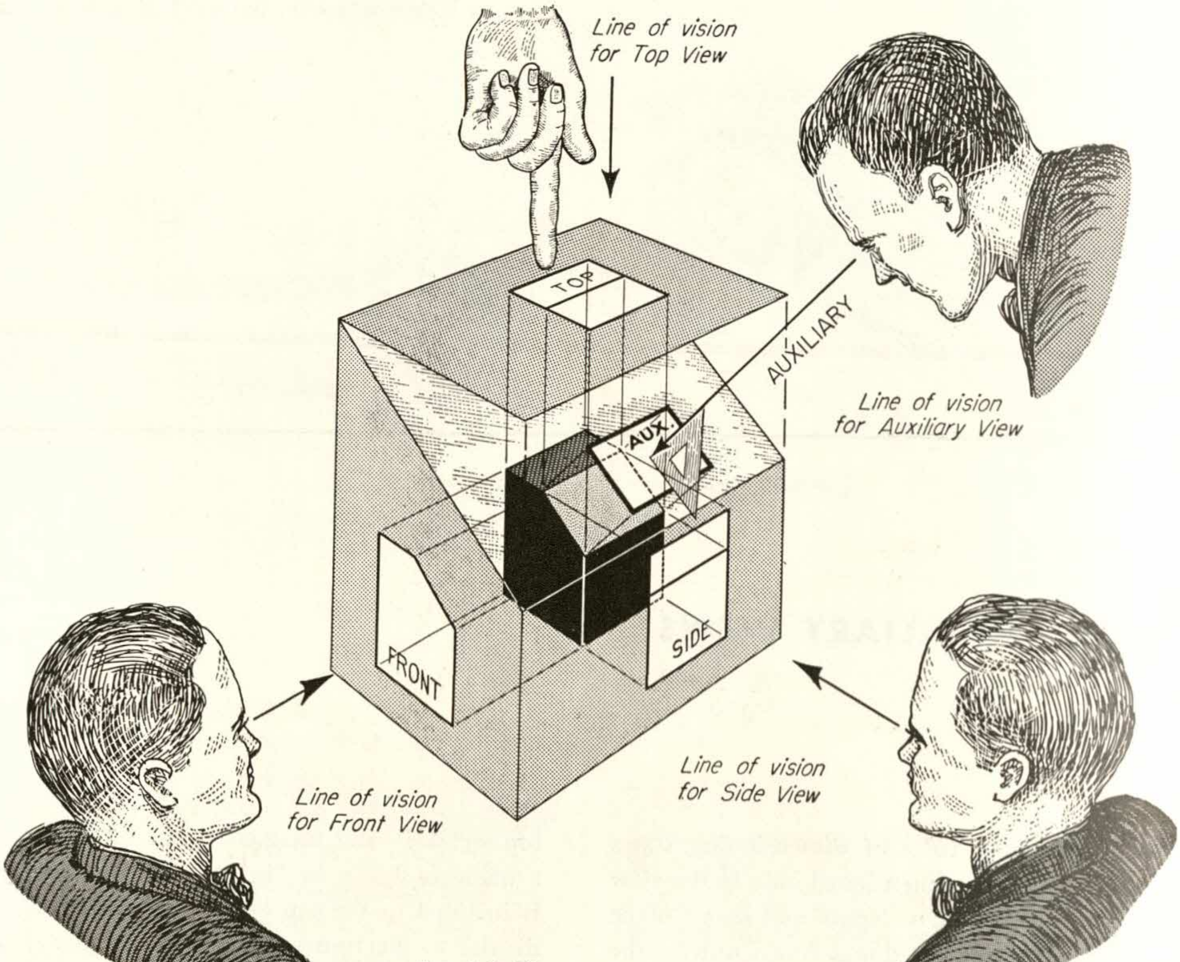
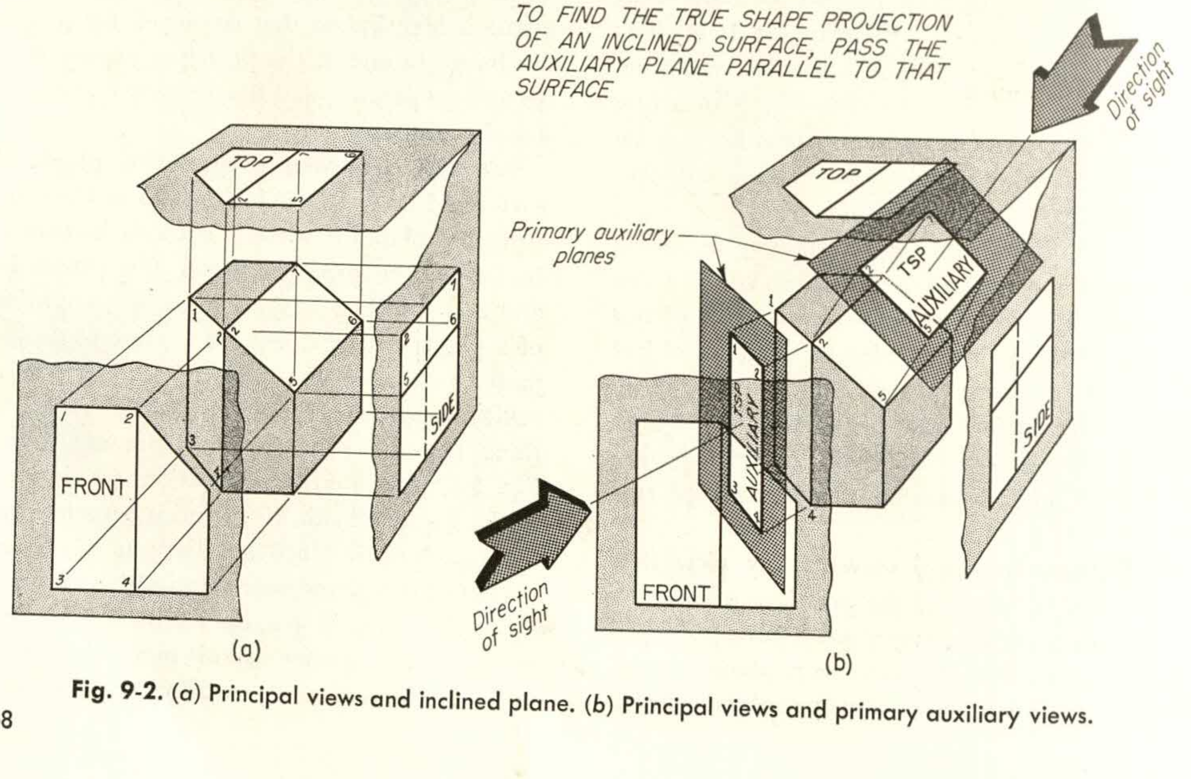


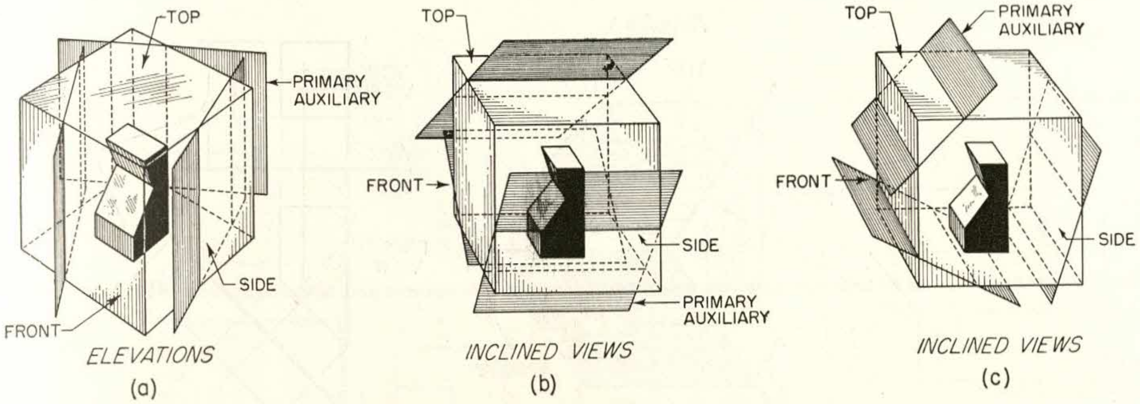
Fig. 9-1. Theory of projection of auxiliary views.


TO FIND THE TRUE SHAPE PROJECTION OF AN INCLINED SURFACE, PASS THE AUXILIARY PLANE PARALLEL TO THAT SURFACE
TOP
FRONT
SIDE
1
2
3
4
5
6
7
Primary auxiliary planes
TSP
AUXILIARY
TSP
AUXILIARY
Direction of sight
Direction of sight

(a)

(b)

Fig. 9-2. (*a*) Principal views and inclined plane. (*b*) Principal views and primary auxiliary views.



ELEVATIONS
(a)

INCLINED VIEWS
(b)

INCLINED VIEWS
(c)

Fig. 9-3. Primary auxiliary views.

passed, setting up these conditions with the principal planes, and still fall in the category of primary auxiliary views. It is important to bear this in mind, since in design work the draftsman often encounters conditions which require auxiliary views that solve problems other than finding the true shapes of planes.

An auxiliary elevation is used to show the true shape of a plane surface that is inclined to the front and side views and perpendicular to the top. The auxiliary plane is passed parallel to the inclined surface and perpendicular to the top and is then rotated into the plane of the paper as if attached to the top view. This procedure is illustrated in Fig. 9-4. Note that the auxiliary view is an additional view; it is the third in the series of front, top, and auxiliary; it is perpendicular to, projected from, and thus adjacent to the top view; and since the front is also adjacent to and perpendicular to the top, the distance from any point in the auxiliary to its reference line (see Sec. 9-4) is the same as the distance from the identical point in the front view to the reference line between the top and front views. This is true because in any three successive adjacent planes of projection the middle plane is always perpendicular to the two extreme planes and the depth dimension of a point will be the same in the extreme planes of the group. (Keep in mind that the reference line denotes the intersection of two planes of projection in a space diagram, and on the drawing paper it is the arbitrary limit of one plane and the edge view of the adjacent plane.)

If a plane surface is perpendicular to the front view and inclined to the top and side views, its true shape may be shown on a plane passed parallel to the inclined surface and perpendicular to the front view (see Fig. 9-5). Here again the auxiliary

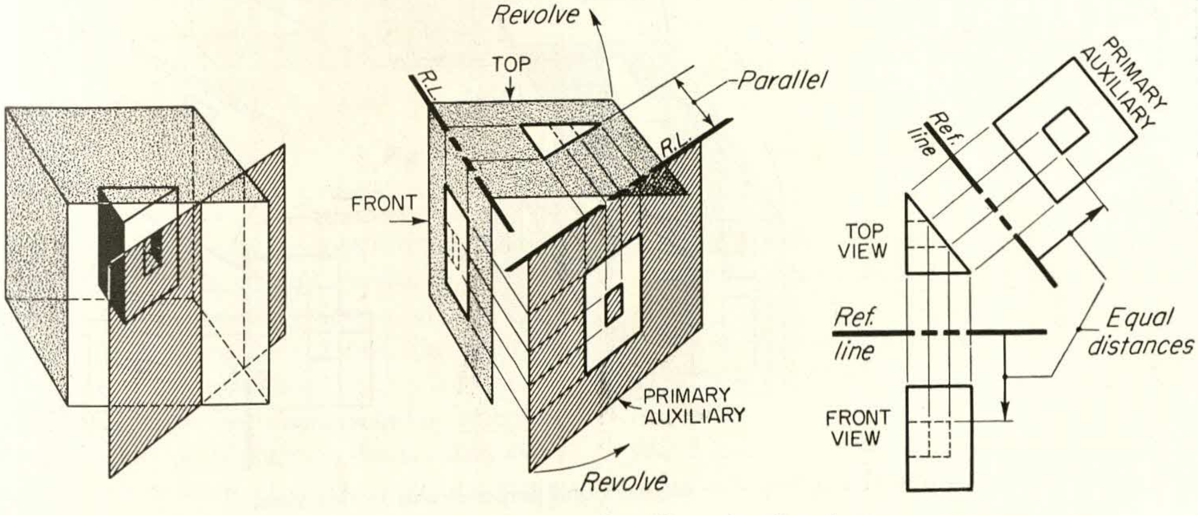


Fig. 9-4. Characteristics of auxiliary elevation views.

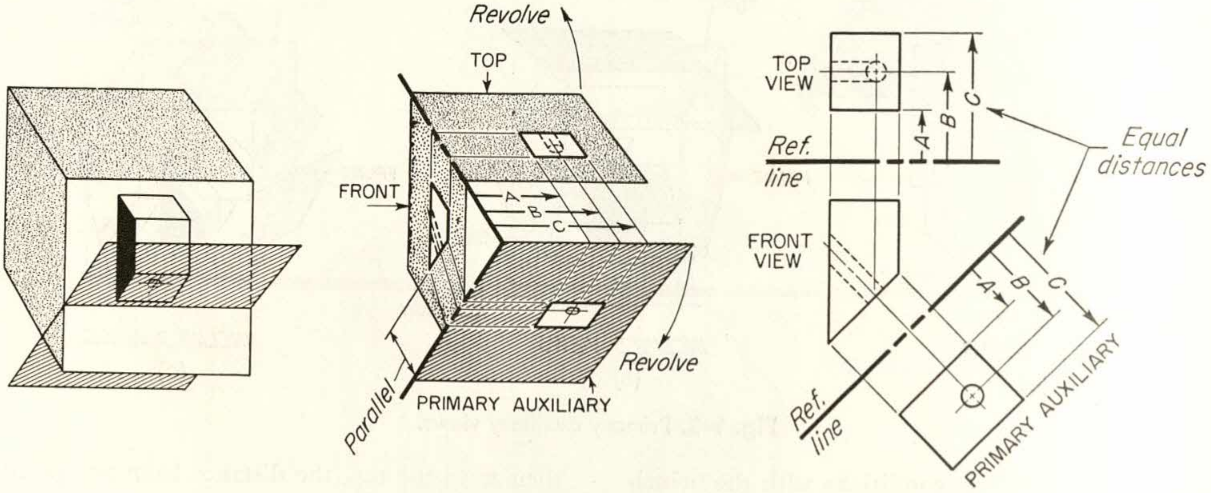


Fig. 9-5. Auxiliary view adjacent and perpendicular to front view.

and the front are attached and adjacent; the front and the top are attached and adjacent. The auxiliary and the top are perpendicular to the front; thus, any point common to the auxiliary and top views will be the same distance from their respective reference lines (that is, distances *A*, *B*, and *C*, for example, will be equal).

If a plane is inclined to the top and front views and is perpendicular to the side, the auxiliary showing the true shape of that plane must be passed parallel to the plane and perpendicular to the side view (see Fig. 9-6). The auxiliary is attached to the side view and passed perpendicular to it. The front is also perpendicular to the side and attached to it. Thus, as noted above, all points common to the front and auxiliary views will be the same distance from their respective reference lines.

9-4. How to draw an auxiliary view. Figure 9-7 illustrates the general procedure followed in the construction of all types of primary auxiliary views. First, draw two adjacent principal views, one of which must show the inclined plane as an edge (line projection). Then, draw a line, which we shall call the *reference line*, parallel to the edge view of the inclined plane whose true shape is to be shown. A reference line is also passed between the two principal views, as shown in the illustration.

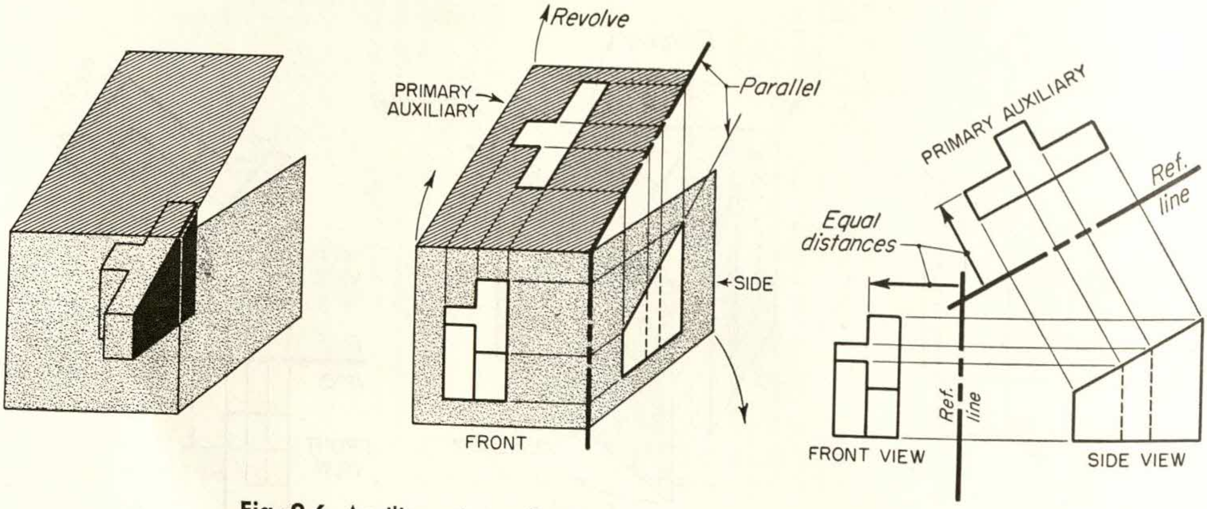


Fig. 9-6. Auxiliary view adjacent and perpendicular to side view.

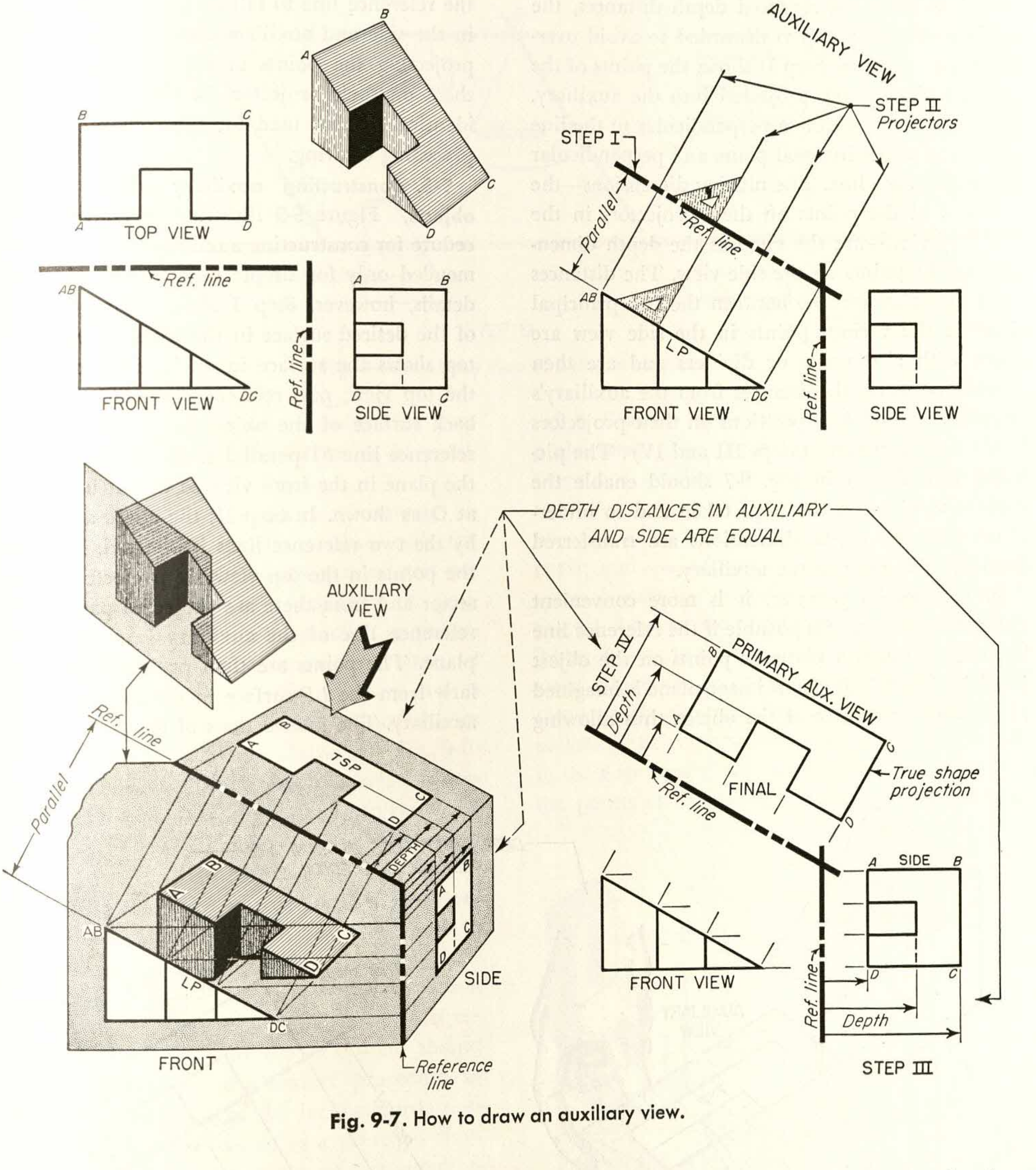


Fig. 9-7. How to draw an auxiliary view.

The reference lines may be considered as folding lines that are placed at any convenient distance that will allow the auxiliary view to fall in a clear space on the drawing sheet. Often, the reference lines can be drawn to coincide with a line on the object itself, as we shall see later. The reference lines are used to locate points in the auxiliary view, and if they have been placed between the views, they are usually erased once the drawing has been completed. Therefore, they should be drawn very lightly.

In Fig. 9-7, the inclined plane *ABCD* is perpendicular to the front view, where it appears as a line projection. In Step I the reference line is passed parallel to the inclined plane at any convenient distance from it. Since both the top and side views show the required depth distances, the top is unnecessary and is discarded to avoid overlapping projections. Step II shows the points of the inclined plane being projected into the auxiliary. The projectors are drawn perpendicular to the line projection of the inclined plane and perpendicular to the reference line. The missing dimensions—the locations of the points on their projectors in the auxiliary view—are the same as the depth dimensions of the points on the side view. The distances from the reference line between the two principal views to the various points in the side view are taken with a compass or dividers and are then transferred as depth distances from the auxiliary's reference line to their positions on their projectors in the auxiliary view (Steps III and IV). The pictorial view shown in Fig. 9-7 should enable the student to visualize the steps taken and to understand why the depth dimensions are transferred from the side view to the auxiliary.

In commercial practice, it is more convenient and greater accuracy is possible if the reference line is passed through a plane or points on the object itself. In Fig. 9-8, the front image plane is imagined resting on the surface of the object, thus allowing the reference line to fall on the same front surface in the side and auxiliary views. The procedure in projecting the points of the object and locating them on their projectors in the auxiliary view is identical to that used for the construction of the preceding drawing.

9-5. Constructing auxiliary views of simple objects. Figure 9-9 illustrates a convenient procedure for constructing auxiliary views. It is recommended only for simple objects consisting of few details, however. Step I shows a line projection of the desired surface in the front view, while the top shows the surface in an inclined position. In the top view, pass reference line *FT* through the back surface of the object as shown. Then, pass reference line *F*1 parallel to the line projection of the plane in the front view so that it intersects *FT* at *O* as shown. In Step II, the angle at *O* formed by the two reference lines is bisected. In Step III, the points in the top view are projected to the bisector and from there are projected parallel to the reference line of the auxiliary into the auxiliary plane. The points are then projected perpendicularly from the *LP* surface in the front view to the auxiliary. The intersections of the projectors from

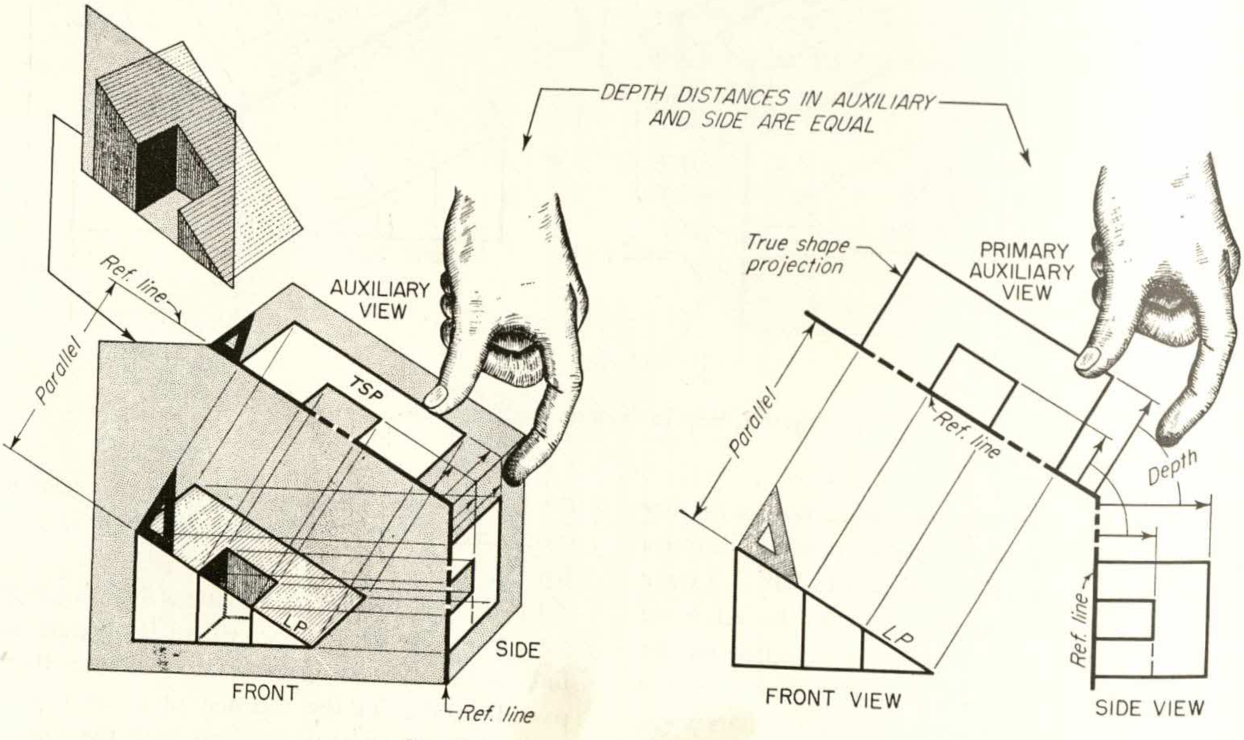


Fig. 9-8. A unilateral auxiliary view.

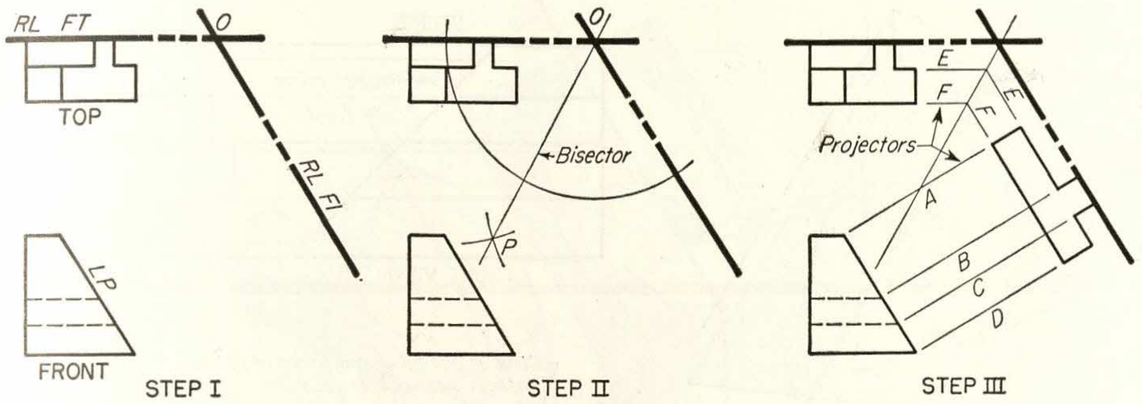


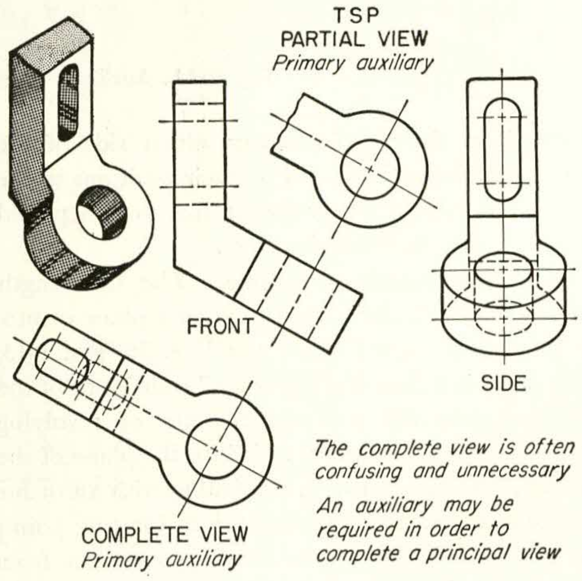
Fig. 9-9. Auxiliary view of a simple object.

the top and front views locate the points and form the true shape of the inclined surface in the auxiliary view.

9-6. Partial auxiliary views. In drawing an auxiliary view, it is customary to show only the shape and details of the inclined surface, and not a view of the entire object as seen from the position of the auxiliary plane. If practice in projection is desired, the entire object may, of course, be drawn. However, this is rarely necessary and is often confusing because of the abundance of lines that appear in the drawing. Notice in Fig. 9-10 that the partial auxiliary is much clearer and less time-consuming to draw than the complete auxiliary, and yet it gives all the necessary information concerning the inclined plane.

9-7. Auxiliary view to complete a principal view. In Fig. 9-10, it is obvious that the side view could not have been completed without having first constructed the true-shape projection shown in the auxiliary view. This situation is encountered frequently, and the draftsman should become familiar with the correct procedure to follow. The view showing the inclined surface as an edge is always constructed as a principal view. From the dimensions available, the auxiliary is drawn on a plane of projection parallel to the edge view. The points of the object are projected back from the auxiliary view to the line projection of the surface in the principal view and then, if required, in the proper manner to the other principal view, the points in this view being located on their projectors the same distance from the selected reference line as they are shown in the auxiliary.

9-8. Circular and curved forms in auxiliary projections. The procedure used to draw the true-shape auxiliary projection of curved surfaces is shown orthographically in Fig. 9-11 and pictorially in Fig. 9-12. Note that the side view of the curve and its adjacent line-projection view are given. Locate any desired points on the curve, and project these to the line projection, or edge view. These points are then projected to the auxiliary view, where the reference plane has been passed conveniently through the center line of the piece to locate the reference line that is drawn parallel to the edge view of the desired surface. In this case, the points of the curve in the auxiliary view are



The complete view is often confusing and unnecessary

An auxiliary may be required in order to complete a principal view

Fig. 9-10. Complete and partial auxiliary views.

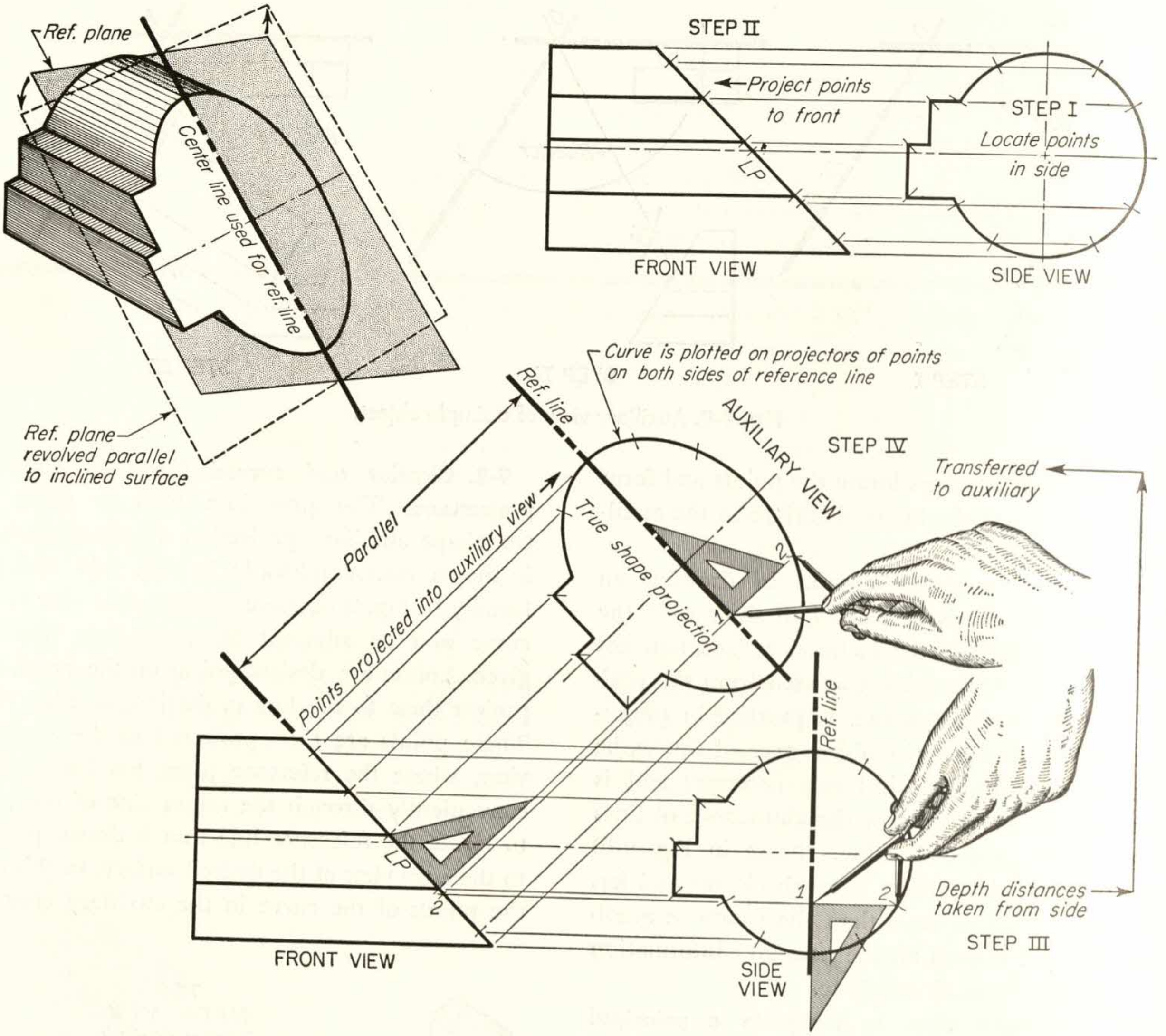

Ref. plane
Center line used for ref. line
Ref. plane revolved parallel to inclined surface
STEP II
Project points to front
STEP I
Locate points in side
LP
FRONT VIEW
SIDE VIEW
Curve is plotted on projectors of points on both sides of reference line
Ref. line
AUXILIARY VIEW
STEP IV
Transferred to auxiliary
Parallel
Points projected into auxiliary view
True shape projection
2
1
Ref. line
LP
2
1
2
FRONT VIEW
SIDE VIEW
Depth distances taken from side
STEP III

Fig. 9-11. Auxiliary of curved forms (bilateral auxiliary).

located on their projectors on either side of the reference line as indicated by their positions in the side view, where the reference line is also passed through the center of the piece.

9-9. True length of a line. The true-length projection of a line is seen only on a plane of projection passed parallel to the line. In Fig. 9-13, the pictorials show the "in space" conditions of the oblique line *AB* and the manner of revolving the plane passed parallel to it into the plane of the paper. The last drawing, coinciding with an orthographic, shows how the dimensions locating points *A* and *B* of the line in the auxiliary are taken from the front view. The orthographic step-by-step procedure is shown below the pictorials. The last drawing of the group shows that a reference plane could have been passed parallel to any given view of the line in order to obtain its true-length projection. See Sec. 15-12 also.

9-10. True length of a line by revolution. Another method by which the true length of a line may be secured, and one that is much used by draftsmen for checking purposes, is illustrated in Fig. 9-14. The line *AB* is considered as the element of a cone, shown obliquely in the principal views. When the line is revolved about the imagined apex of the cone (point *A*) parallel to the plane of projection in the top view and the revolved position of the point *B* is projected to the front view, the line will appear as a true-length projection because it takes the same position as an extreme element of the cone, which would be seen

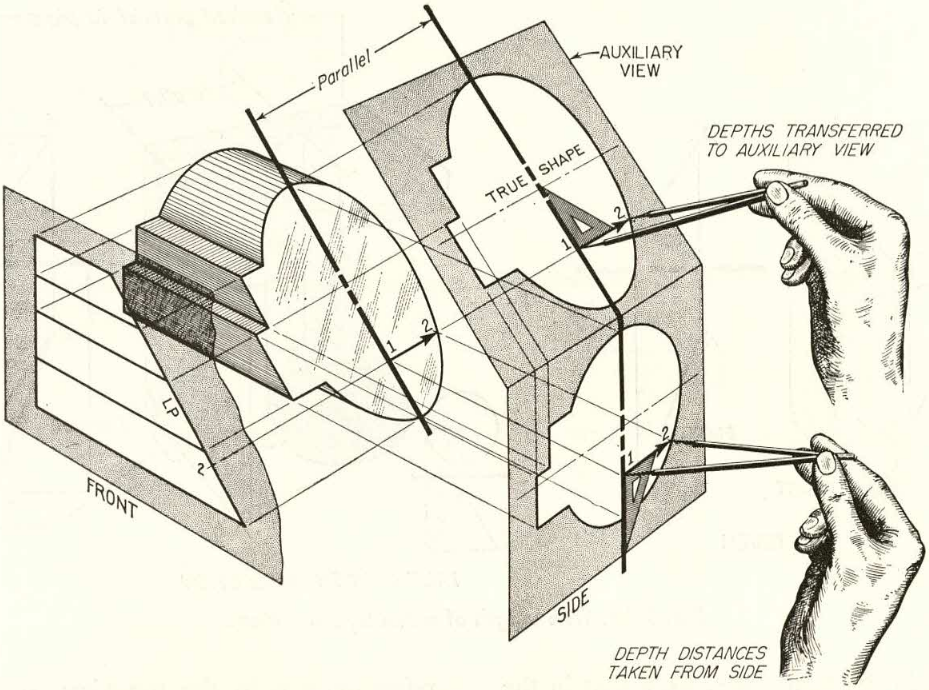

Parallel
AUXILIARY VIEW
DEPTHS TRANSFERRED TO AUXILIARY VIEW
TRUE SHAPE
1
2
1
2
LP
2
FRONT
1
2
SIDE
DEPTH DISTANCES TAKEN FROM SIDE

Fig. 9-12. Pictorial of procedure for drawing auxiliary of curved forms.

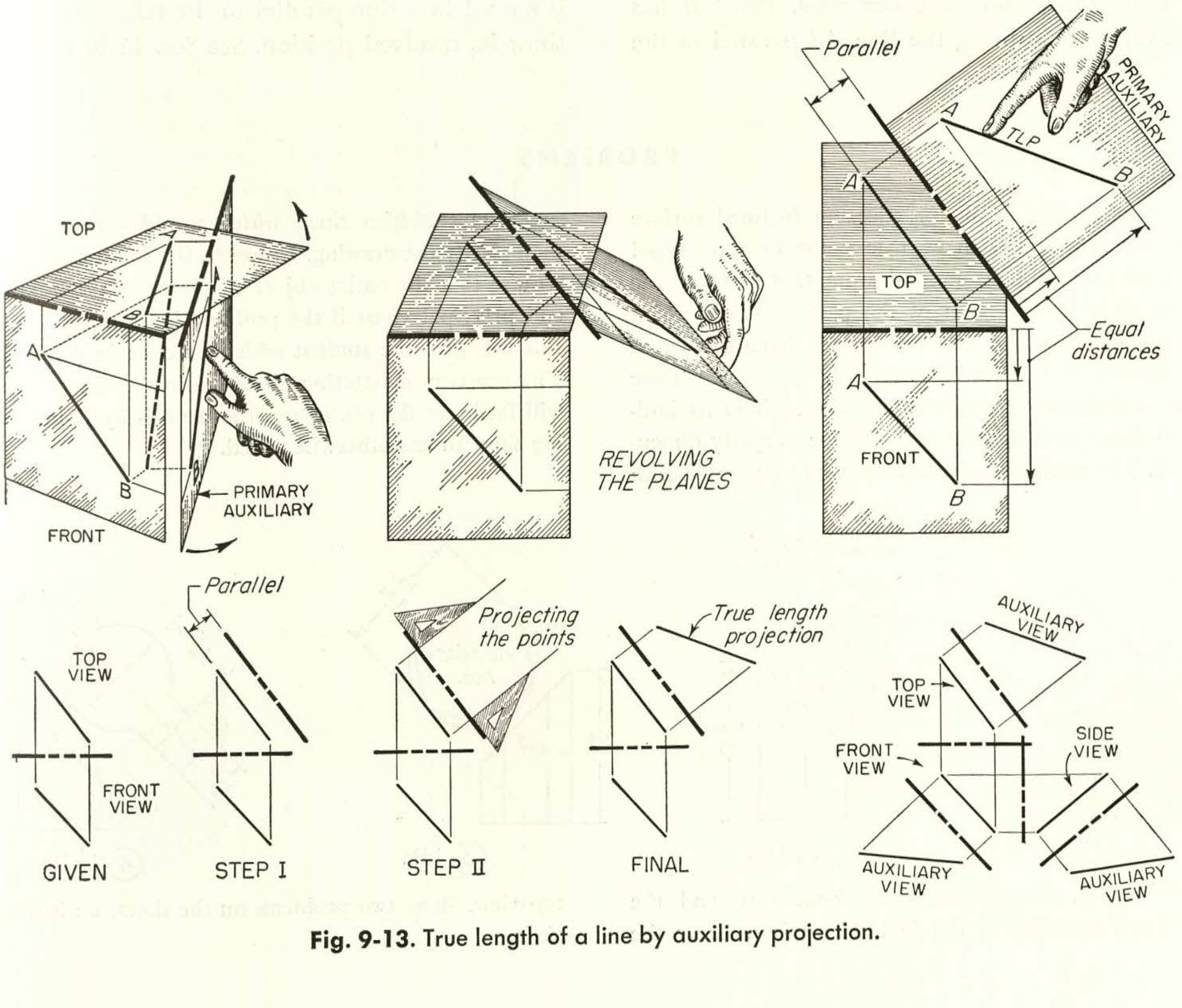
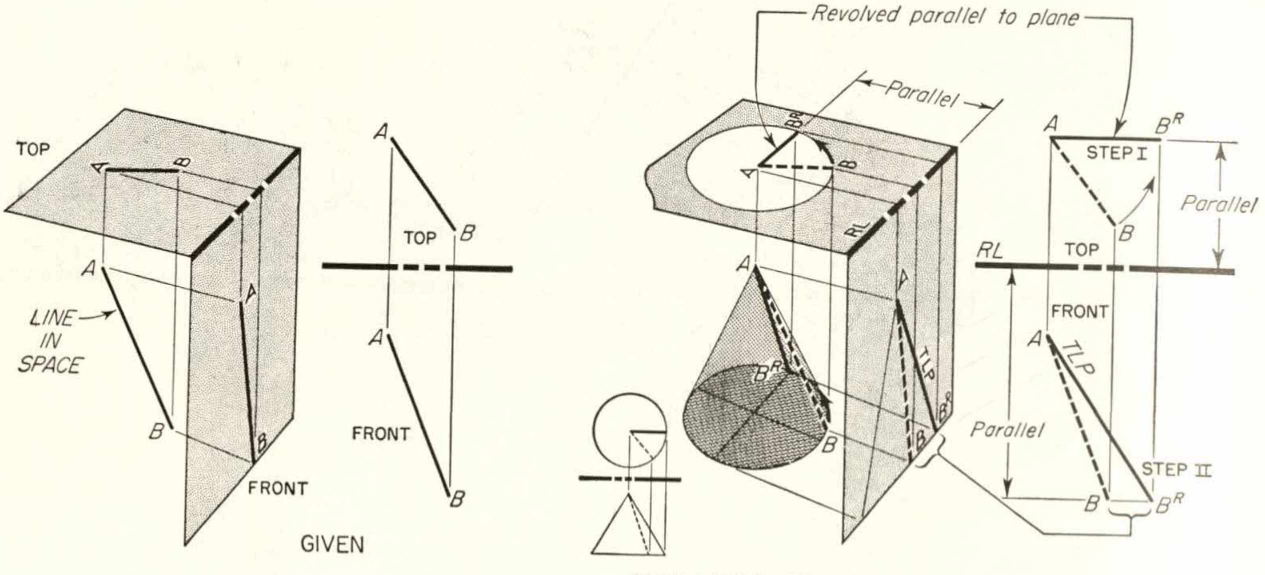


Fig. 9-13. True length of a line by auxiliary projection.



GIVEN

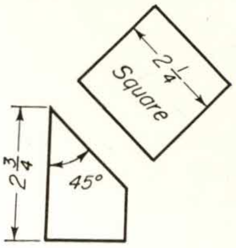
TRUE LENGTH PROJECTION

Fig. 9-14. True length of a line by revolution.

in true length in the front view. Note that in the act of revolution the point *A* has not moved from its original position in either view. Point *B* has been revolved to bring the line *AB* parallel to the reference line in the top view. It was projected from its revolved position to the front view, where it moved in a line parallel to the reference line to show its revolved position. See Sec. 15-46 also.

PROBLEMS

In commercial-drafting practice, an inclined surface that does not appear in its true shape in a principal plane of projection is omitted from that view of the object. Only that portion of the part is drawn which will permit true-shape and true-length dimensioning of the surfaces and their features. The inclined surface alone is projected to an auxiliary view, where its individual shape and features may also be properly dimensioned. The auxiliary view need not be overloaded with superfluous hidden lines, which would confuse rather than clarify the drawing. However, the instructor should require that the entire object be drawn in the auxiliary and principal views if the problem is a simple one, for this will give the student added practice in projection. The practice of lettering all the points to be projected will facilitate the procedure. Use an 8½- by 11-in. drawing sheet unless otherwise noted.



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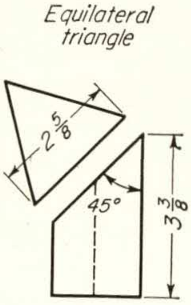
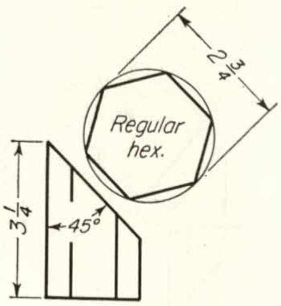
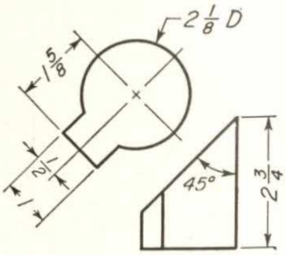


② 1 Hr.

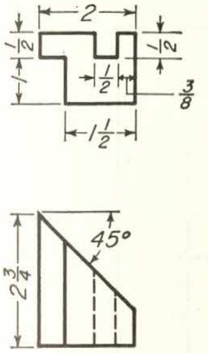


③ 1 Hr.

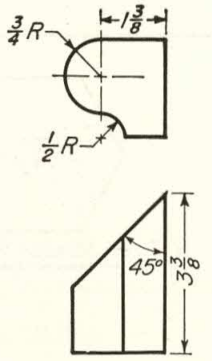


④ $1\frac{1}{2}$ Hr.

9-1 to 9-4. Redraw the given front view and the true-shape auxiliary of the inclined surface. Draw the top view. Show two problems on the sheet; omit dimensions.

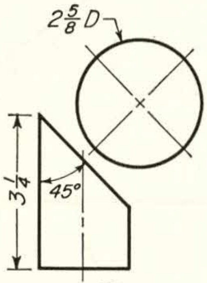


⑤ 1½ Hr.

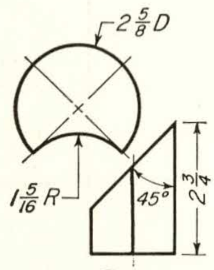


⑥ 1½ Hr.

9-5 and 9-6. Redraw the given front and top views. Project the entire object to the auxiliary view, which will show the true-shape projection of the inclined surface. Omit dimensions.



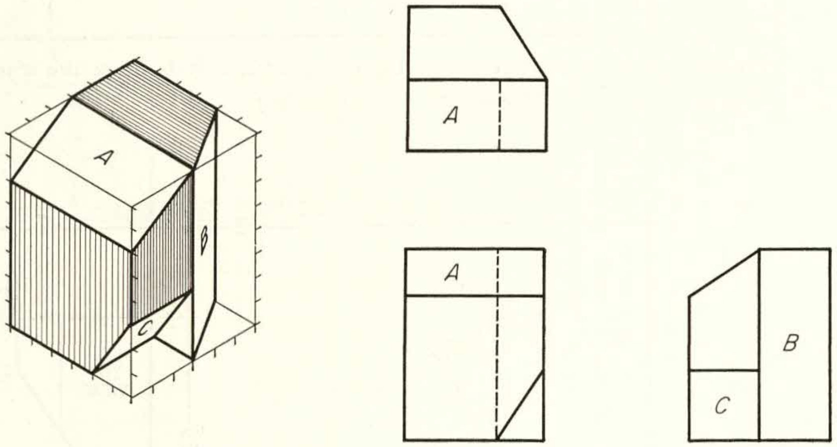
⑦ 1½ Hr.

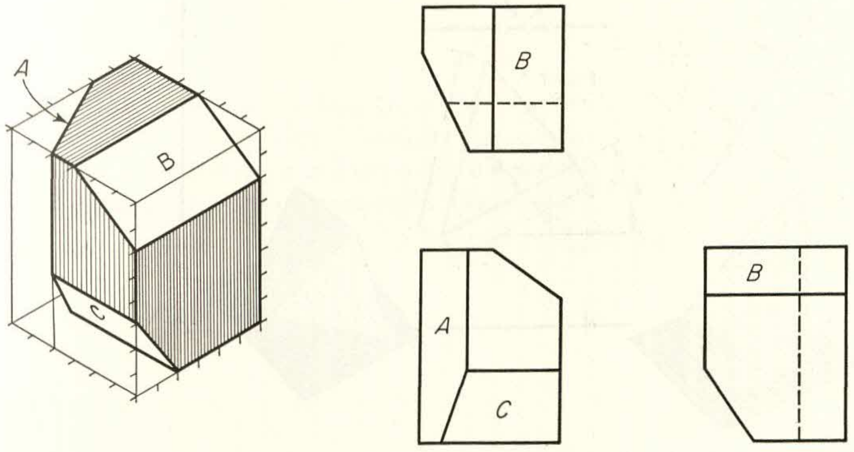


⑧ 1½ Hr.

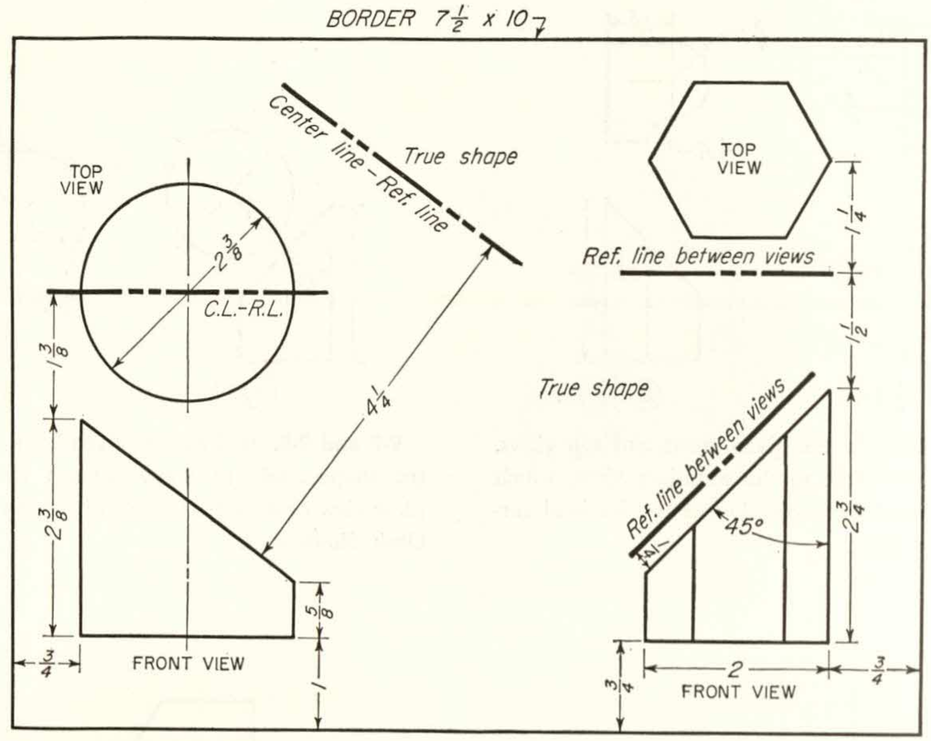
9-7 and 9-8. Redraw the given front view and partial true-shape auxiliary. Show the top view. Show a complete view of the object as seen from the auxiliary plane. Omit dimensions.

9-9. Reproduce the given three views of the object. Find the true shapes of planes *A*, *B*, and *C* inclined to the principal views. Omit all dimensions. Use dividers to transfer the views to your sheet at a suitable scale. (Time. 1½ hr.)

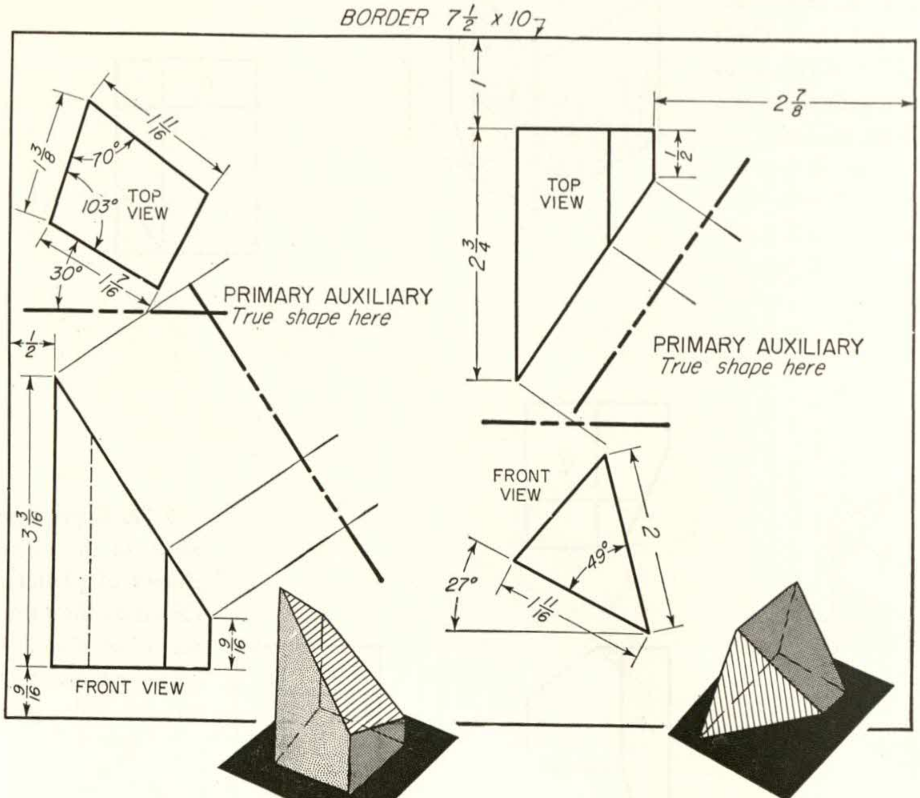




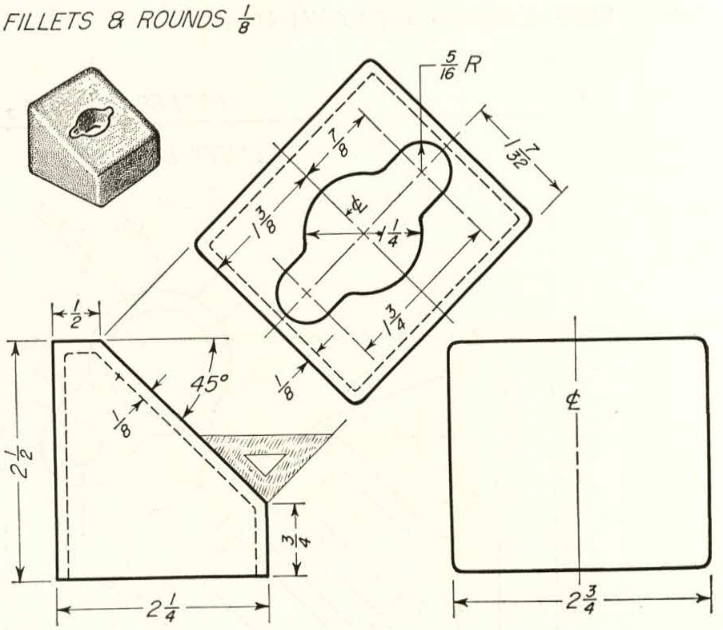
9-10. Reproduce the given three views of the object. Find the true shapes of planes *A*, *B*, and *C* inclined to the principal views. Omit all dimensions. Use dividers to transfer the views to your sheet at a suitable scale. (Time. 1½ hr.)



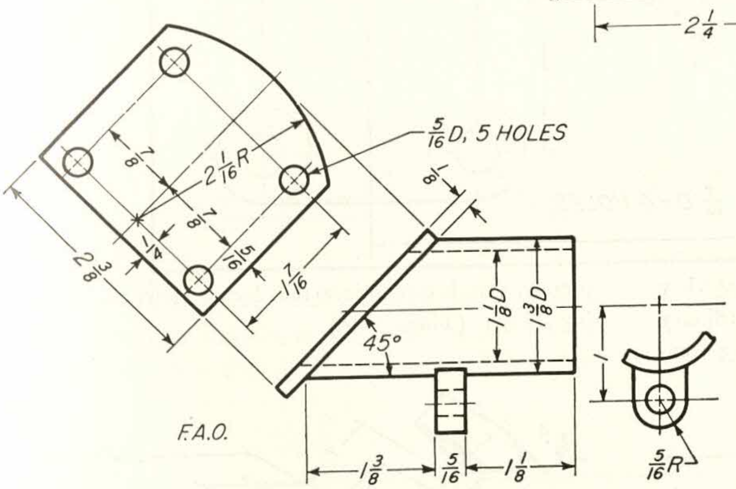
9-11. Reproduce the given front and top views of the objects. Show the true shape of the inclined surfaces in the auxiliary views. Omit all dimensions. (Time. 2½ hr.)



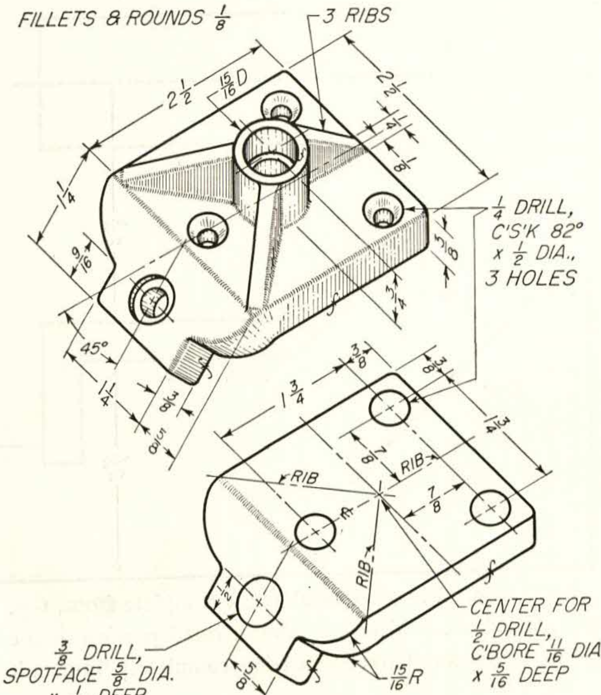
9-12. Reproduce the given top and front views of the objects. Show the true shape of the inclined surfaces in the auxiliary views. Omit all dimensions. (Time. 2½ hr.)



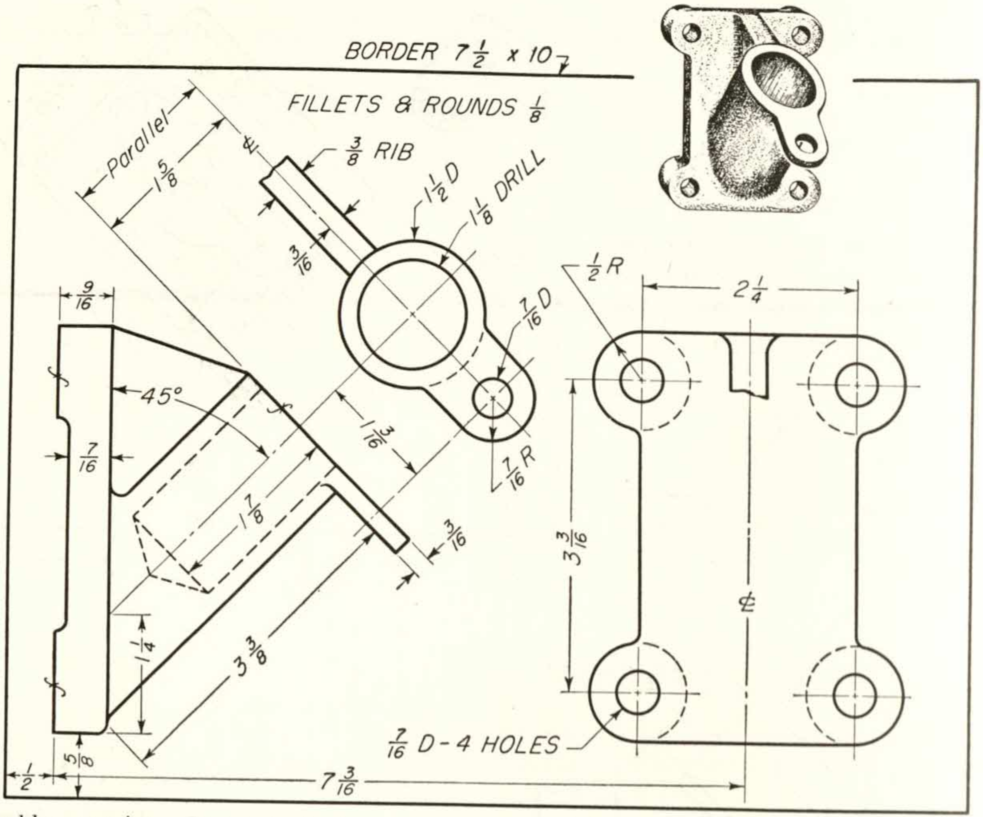
9-13. Switch cover, cast iron. Complete the front view as a full section view. Show the side in ordinary orthographic projection. Dimension the drawing completely. (Time. 2½ hr.)



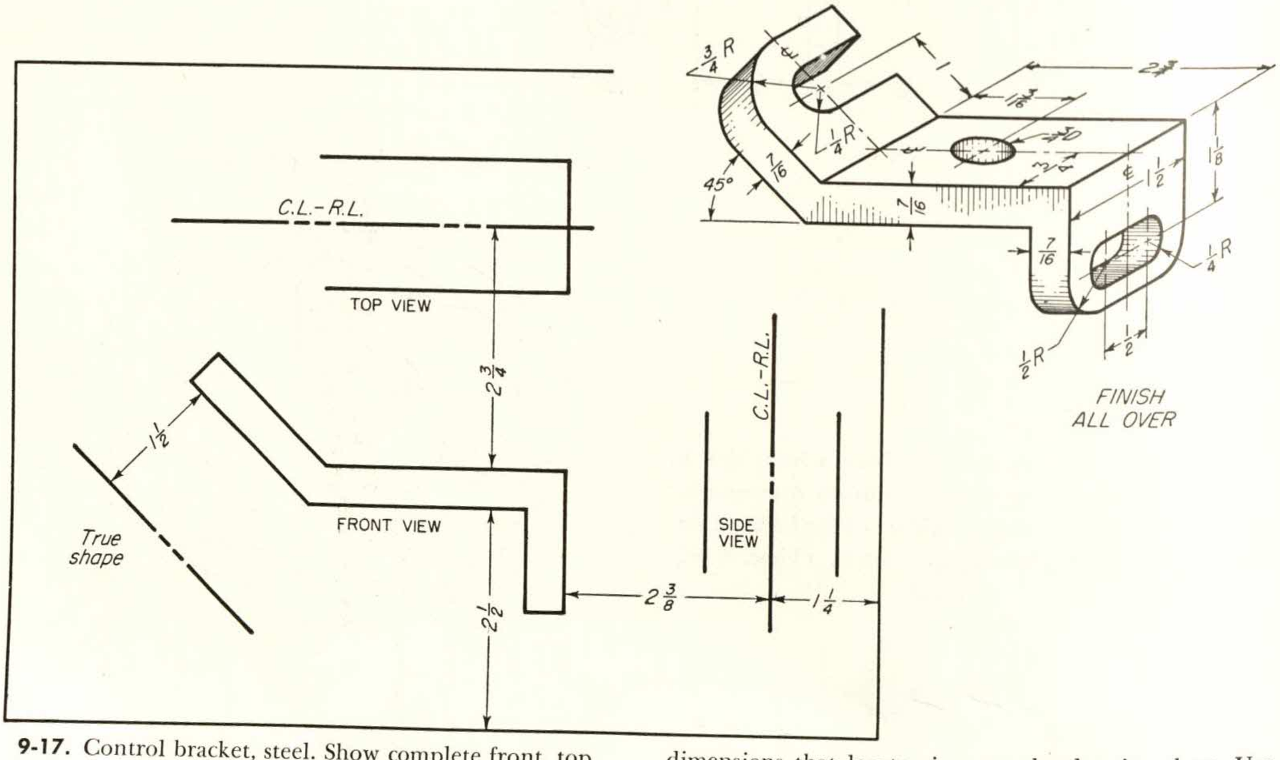
9-14. Pole bracket, cast iron. Complete the auxiliary view. Draw a top and side view. Dimension completely. (Time. 3 hr.)


FILLETS & ROUNDS 1/8
3 RIBS
2 1/2
15/16 D
2 1/2
1/4
1/8
1 1/4
9/16
1/4 DRILL, C'S'K 82° x 1/2 DIA., 3 HOLES
5/8
3/4
45°
1 1/4
3/4
5/8
1 3/4
3/8
3/8
3/4
7/8
RIB
RIB
7/8
RIB
1/2
5/8
15/16 R
3/8 DRILL, SPOTFACE 5/8 DIA. x 1/16 DEEP
CENTER FOR 1/2 DRILL, C'BORE 11/16 DIA. x 5/16 DEEP

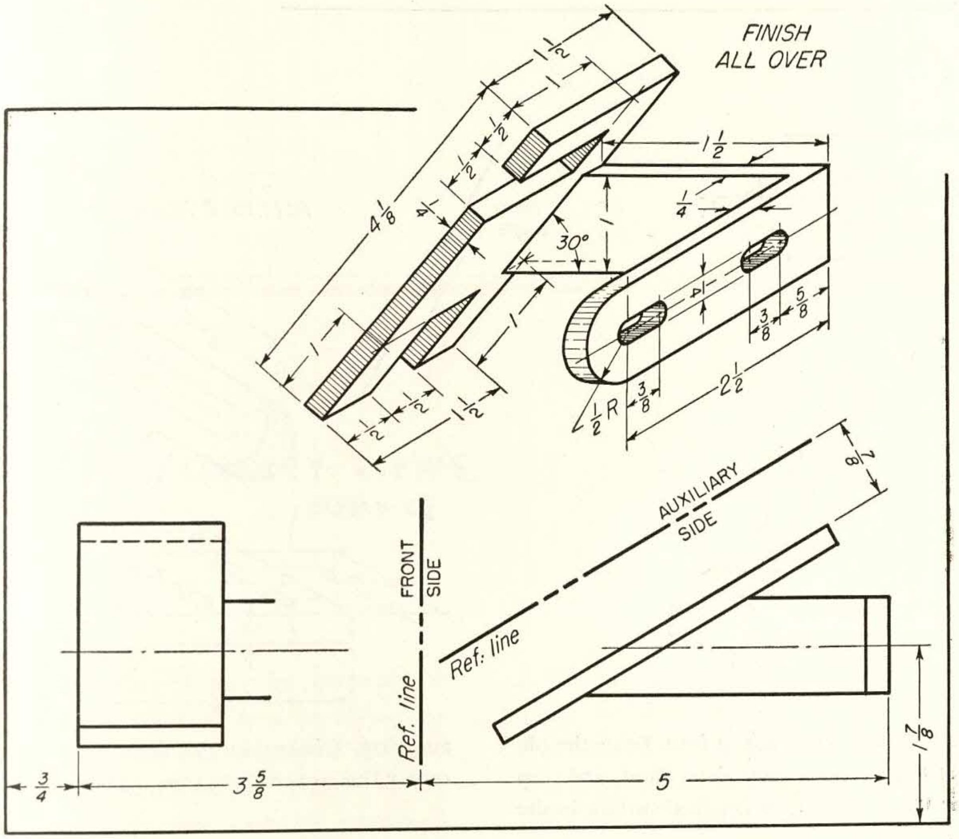
9-15. Bearing support, cast iron. Draw a front view in full offset section, a top view in ordinary orthographic projection, and a true-shape auxiliary of the inclined surface. Dimension the drawing completely. (Time. 4 hr.)



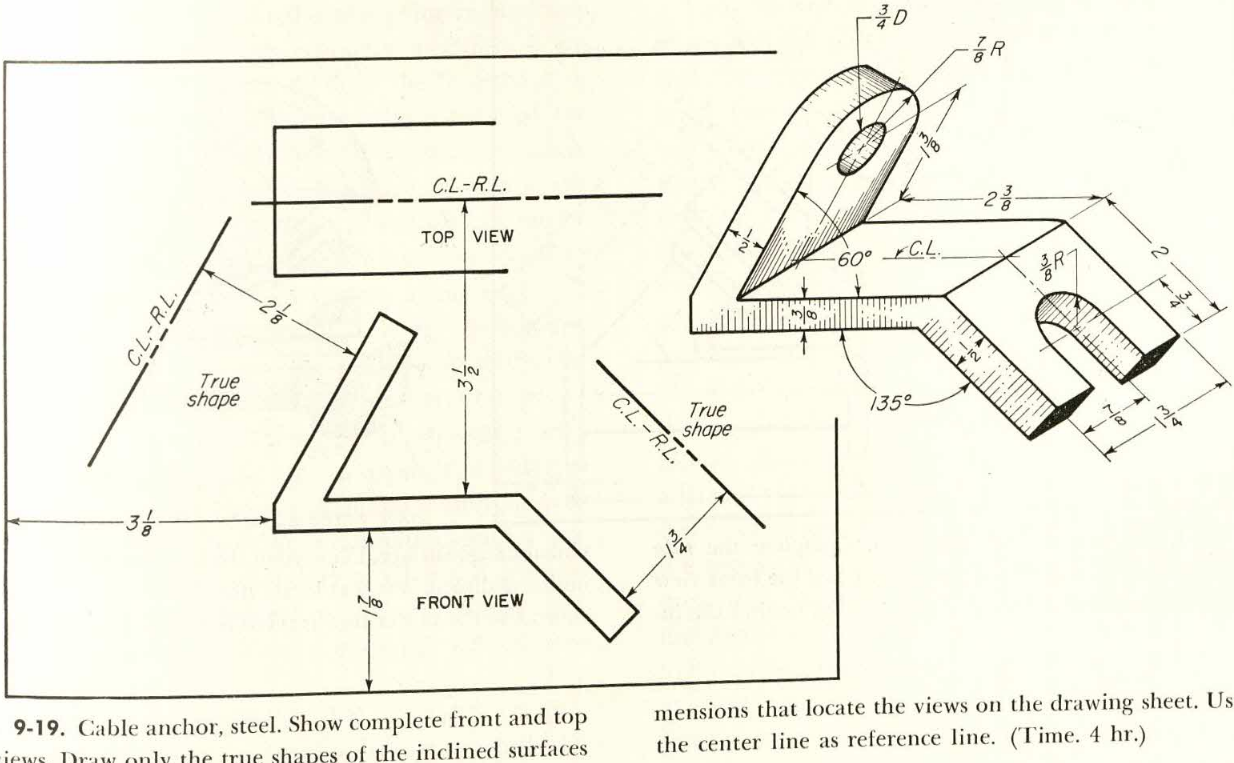
9-16. Pole holder, cast iron. Complete the front view as an offset section view. Show the side as an ordinary orthographic projection. Dimension your drawing completely. (Omit dimensions that locate views on the drawing sheet.) (Time. 4 hr.)



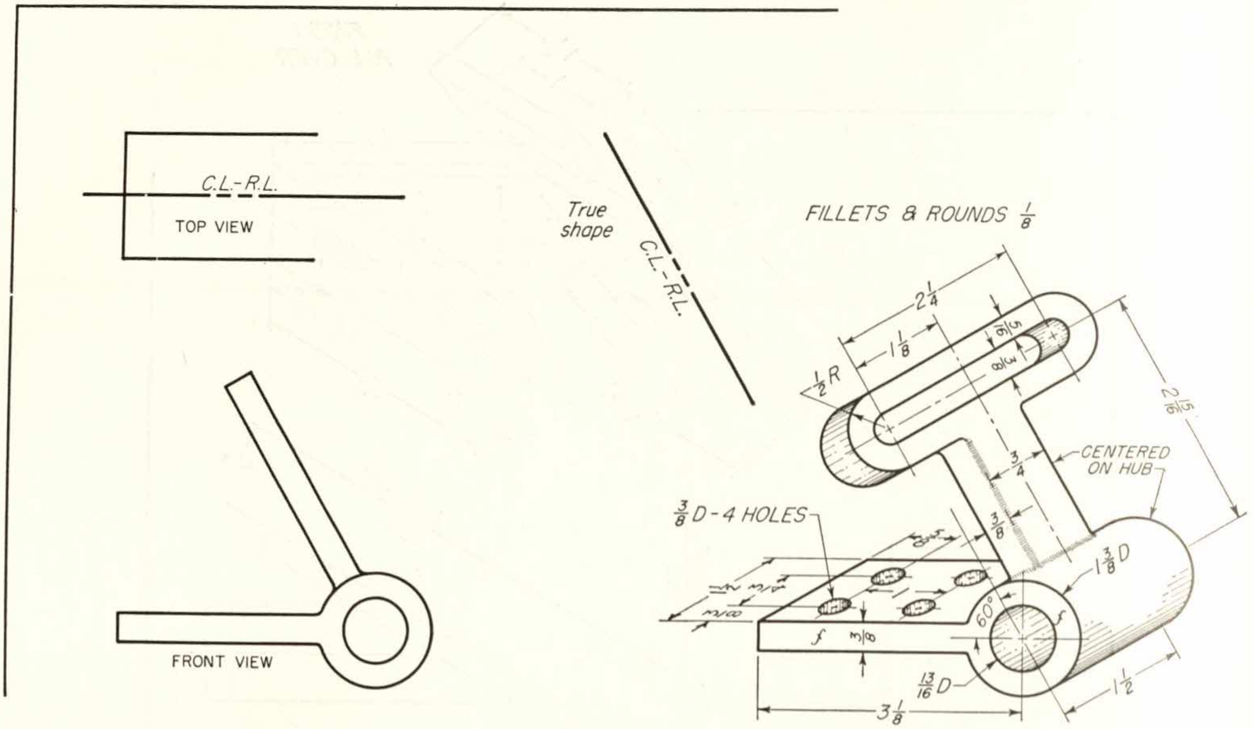
9-17. Control bracket, steel. Show complete front, top, and side views. Project only the inclined portion of the object to the auxiliary. Dimension completely, but omit dimensions that locate views on the drawing sheet. Use the center line as reference line. (Time. 3½ hr.)



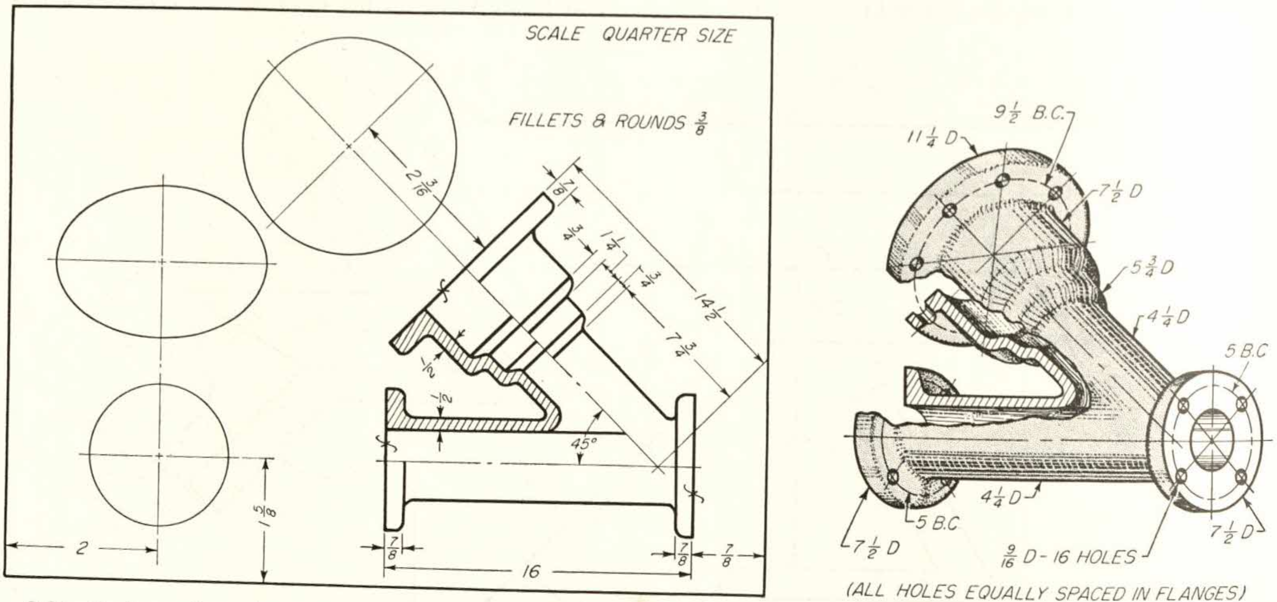
9-18. Belt guide, aluminum. Complete the given front and side views. Show only the inclined surface in the auxiliary view. Dimension completely, but omit dimensions that locate views on the drawing sheet. (Time. 3 hr.)



9-19. Cable anchor, steel. Show complete front and top views. Draw only the true shapes of the inclined surfaces in the auxiliaries. Dimension completely, but omit dimensions that locate the views on the drawing sheet. Use the center line as reference line. (Time. 4 hr.)



9-20. Adjustable shaft support, cast iron. Draw the object three-quarter size. Show complete front and top views. Draw the true shape of the inclined surface in the auxiliary. Dimension the drawing completely. Use the center line as reference line. (Time. 4 hr.)



9-21. Reducer lateral, cast iron. Complete the side view and the flange in the auxiliary. Draw the front view with a minimum of hidden lines showing behind the inclined flange surface. Dimension the drawing completely, omitting dimensions that locate the views on the drawing sheet. Use the center line as reference line. (Time. 5 hr.)

Chapter 10

SECONDARY AUXILIARY VIEWS

There are times when it may be necessary to show the true-shape projection of a plane surface that does not appear as an edge in any of the principal views. In these circumstances, what is known as a *secondary auxiliary view* must be drawn. A secondary auxiliary view (also called a "double auxiliary view") may be defined as a projection on a plane that lies oblique to *all* the principal planes or views. It is perpendicular to a primary auxiliary plane, from which the secondary auxiliary is *always* projected. In order to draw the true shape of an oblique surface, a line-projection view of the surface must be found. Since the secondary auxiliary plane lies oblique to the principal planes, the necessary line-projection view of the surface can be obtained only by first drawing a primary auxiliary view showing the desired surface as an edge.

Throughout engineering-drawing procedure, practically all drafting requisites can be satisfied by utilizing four, or possibly five, different types of planes of projection, namely, two adjacent principal planes (front and top or front and side), a primary auxiliary, and a secondary auxiliary; or three principal planes in combination with a primary auxiliary and secondary auxiliary. *A primary auxiliary is always projected from a principal view, and a secondary auxiliary is always projected from a primary auxiliary.*

Any plane of projection that is passed (or projected) from another plane is always perpendicular to the plane from which it is projected. A plane (flat) surface is seen in its true shape only when it lies parallel to the plane of projection. If the surface does not show as a line projection in a principal view, a primary auxiliary view must be taken to show it in this manner, after which a secondary auxiliary is passed parallel to the line projection to show the plane in its true shape.

10-1. To find the line projection, or edge view, of an oblique plane. Figure 10-1 shows the front and top views of a triangular solid that has a lower base parallel to the top view and an upper base *ABC* lying oblique to the three principal planes. By descriptive geometry, if we can draw a view in which a line lying in an oblique plane shows as a point, then this same view will show a line projection of the oblique plane. The point projection of a line can be secured only by projecting it from the view showing the true length of the line. It is also a fact that any line in one view that is parallel to its reference line for that projection plane will show in its true length in the adjacent view. Obviously, no line of the plane *ABC* shows in its true length in either the front view or the top view. Therefore, in the top view an arbitrary line *DC* is drawn parallel to the reference line between the front and top views so that the line may be projected and appear in its true length in the front view (as in Step I). (The procedure could have been reversed by drawing an arbitrary

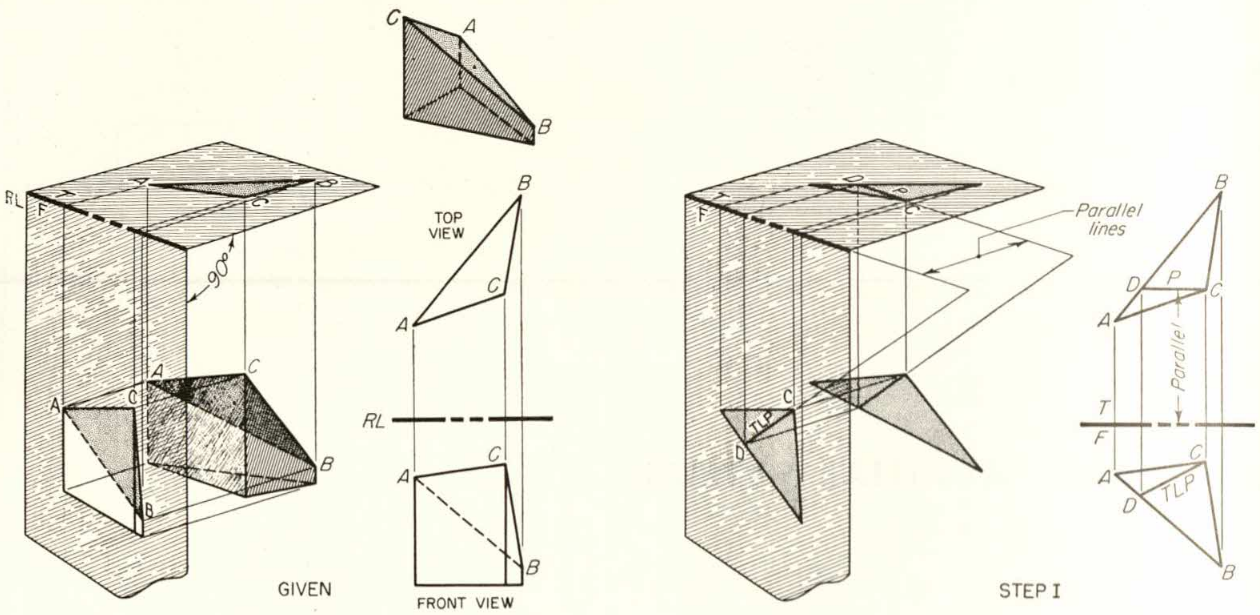


Fig. 10-1. Projection of an oblique plane in the principal views.

line in the front view parallel to the reference line and projecting it to the top view, where it would appear in its true length.)

Step II in Fig. 10-2 indicates the manner in which the point projection of the line and the line projection of the plane are secured. Draw the reference line of the primary auxiliary perpendicular to the true-length projection of *DC* in the front view. Project points *D* and *C* of the line and points *A, B,* and *C* of the plane into the primary auxiliary, locating their positions on their projectors by taking their depth distances with a compass or dividers in the top view and transferring these to the auxiliary. If the draftsman has worked carefully, the line *CD* will show as a point and the plane *ABC* will show as an edge in the primary auxiliary view.

10-2. Finding the true shape from the edge view. The procedure for drawing the true shape of the plane after the edge view has been found is similar to that followed in the previous chapter, where the edge view appeared in a principal view instead of the primary auxiliary (see Fig. 10-3, Step III). The reference line between the primary

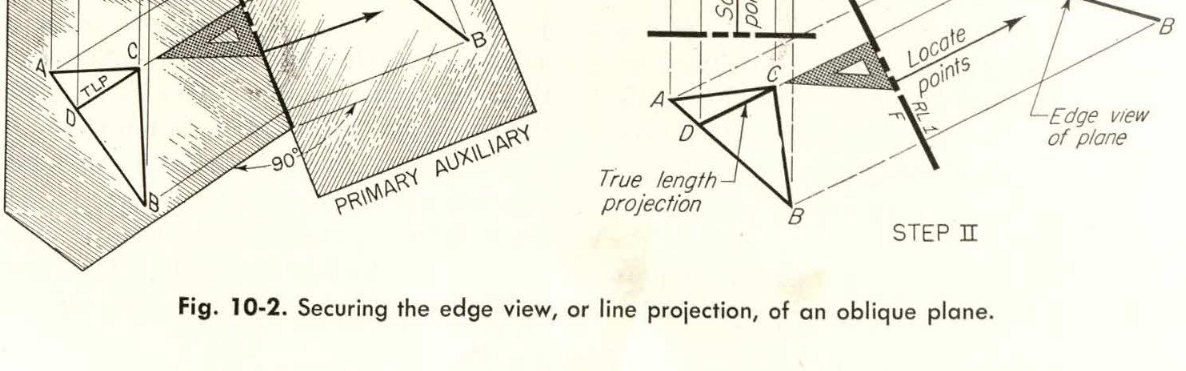


Fig. 10-2. Securing the edge view, or line projection, of an oblique plane.

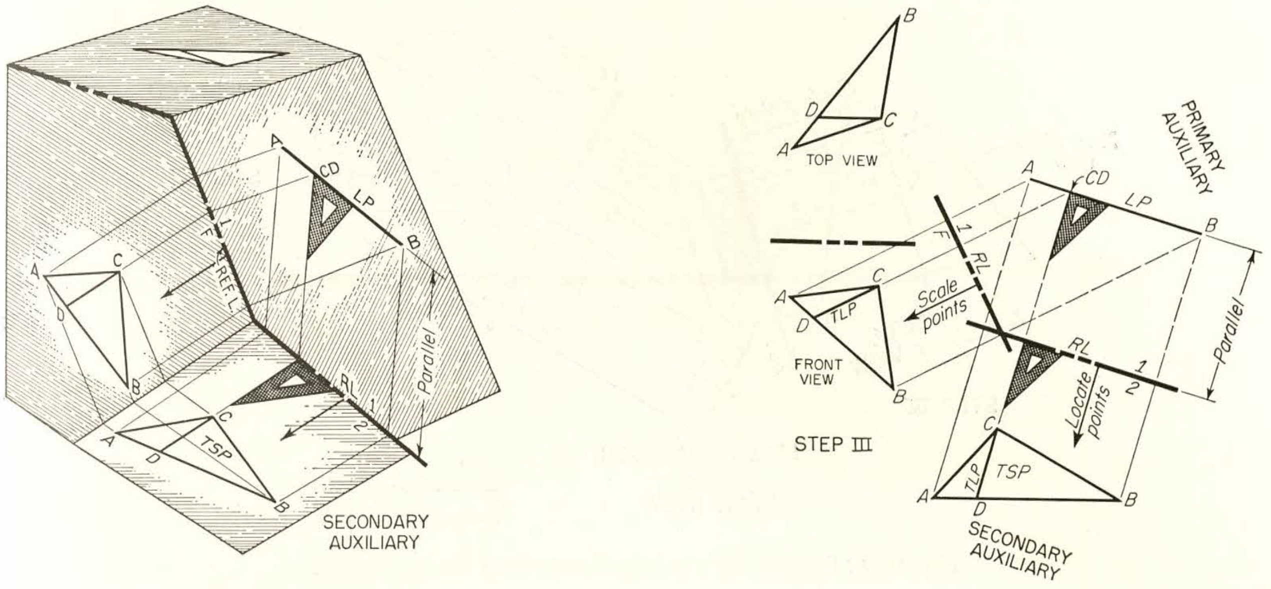


Fig. 10-3. Securing the true shape of a plane from its edge view.

and secondary auxiliaries is passed parallel to the line projection, or edge view, of the plane *ABC* as seen in the primary auxiliary. The points of the plane are projected perpendicular to the reference line into the secondary auxiliary view, where they are located by scaling their distances from the reference line to their positions in the front view and transferring these distances to the point projectors in the secondary auxiliary view. The line *CD* may also be carried to this view, where it will show as a true-length projection and may be used as a check on the accuracy of the work by comparing it with its true-length projection in the front view. Any details of construction appearing in the plane, such as holes or slots, may now be drawn and dimensioned in this view and their shapes brought back through the edge view to the principal views by the process of reversing the projection procedure.

10-3. Practical application and procedure. The pictorial of Fig. 10-4 shows an angle bracket that is to be represented orthographically and completely dimensioned. After studying the object, it has been decided that four views are required as indicated by the arrows: a front view parallel to the front surface of the base, a top view parallel to the top surface of the base, a primary auxiliary perpendicular to the line *AB* (which is common to

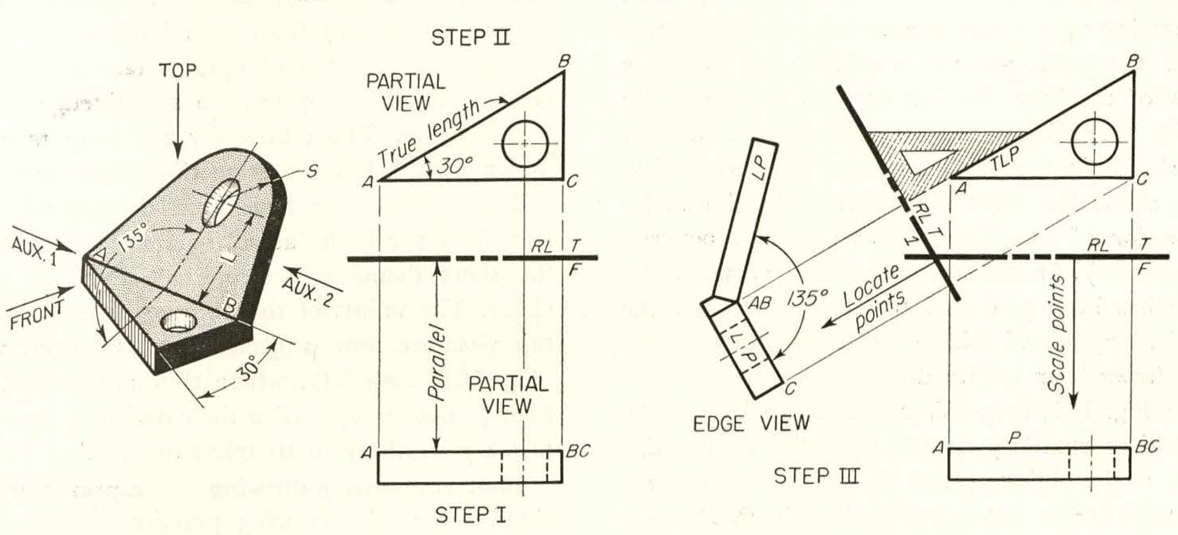


Fig. 10-4. Practical application of auxiliary views.

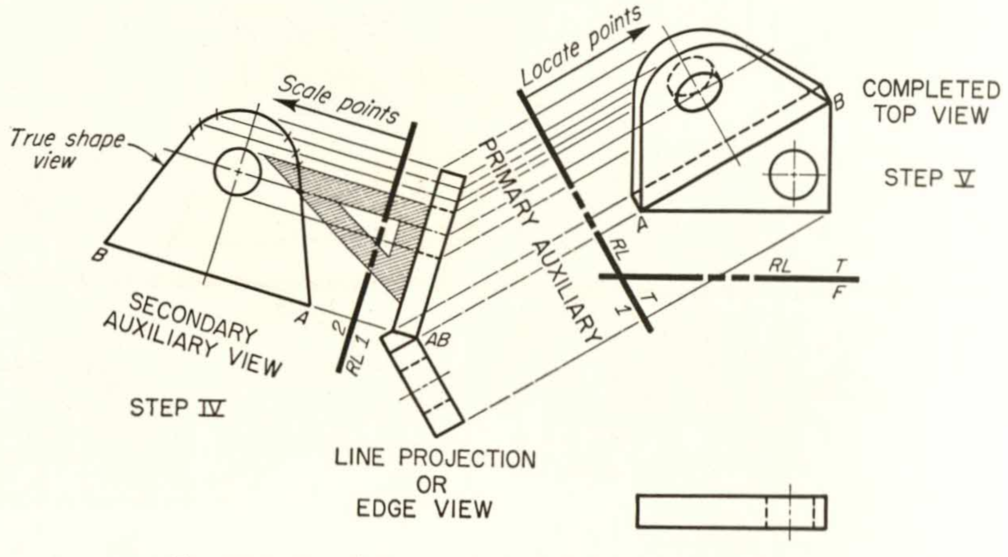


Fig. 10-5. Completing a principal view from the auxiliaries.

both lugs), and a secondary auxiliary parallel to the curved lug.

In Step I, only the triangular base and its hole can be shown in the top and front views. The oblique surface can be represented in the principal views only after its true shape is shown in a secondary auxiliary and projected back, point by point, through the primary auxiliary and then to the principal views.

Since the line *AB* in the front view is parallel to the reference line of the adjacent (top) view, it appears in its true length in the top view. (If a line already appears as a true-length projection in a view, there is no need to pass a parallel in one view to find its true length in the adjacent view.) Now, by setting up a primary auxiliary plane that will show the point projection of *AB* and the edge view of the base *ABC,* as in Step III, the angle which the oblique surface makes with the base can be shown in the auxiliary view (because a view that shows the point projection of the line of intersection of two planes shows the angle between the planes). In this primary auxiliary view, the base has been projected to its position, and the angle, length, and thickness of the oblique surface are drawn from known dimensions.

In Fig. 10-5, Step IV, the reference line of the secondary auxiliary is passed parallel to the edge view of the oblique plane. In this view, the points *A* and *B* are located by taking their depth distances from the reference line to the top view and transferring these to their projectors in the secondary auxiliary. The representation of the remaining portion of the oblique surface and of the hole on its center lines is accomplished by using the dimensions on the object.

The remainder of the task is now simply a matter of locating as many points as are necessary on the true shape in the secondary auxiliary and projecting these points back to both surfaces of the oblique plane, shown as edge views in the primary auxiliary. From these two surfaces in the primary auxiliary, the points are projected perpendicular to the reference line into the top view (Step V), where their positions on their projectors are located by scaling the distances of the points in the secondary auxiliary from its reference line. The representation of the oblique surface in the top view is completed by using a straightedge and a french curve. The ellipse for the hole may be drawn by the four-center method after the long and short diameters have been determined (the long diameter is the actual diameter of the hole; the short diameter is projected from the edge view). The points of the oblique surfaces in the top view are now projected into the front view (Fig. 10-6, Step VI), where they are located on their projectors by scaling their distances from the primary auxiliary to its reference line.

10-4. Engineering-drawing representations. Good engineering-drawing practice requires that at least two adjacent views of a complex object be

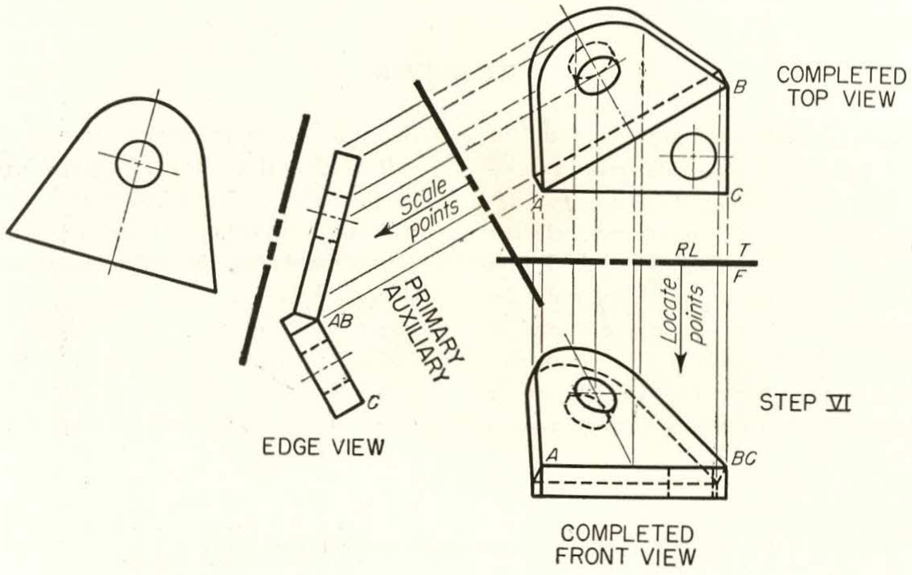


Fig. 10-6. Completing the principal views.

complete representations. These two views are generally principal views. Auxiliary views, therefore, need be only partial views that show the true sizes and shapes of details drawn on their inclined or oblique planes. Good practice also requires that adjacent views be placed in their proper projected relationship to the other views on the drawing sheet to facilitate reading the drawing. For the same reason, the rule that dimensions be given only on true-length and true-shape projections should not be violated. On the final drawing sheet, only one or two of the main projection lines between one auxiliary and another and between an auxiliary and a principal view should be retained, and the reference lines between the views should be omitted.

Figure 10-7 shows the principal views and the required auxiliaries of the object shown in Fig. 10-4, properly dimensioned and arranged in their correct relationship to one another on the drawing sheet.

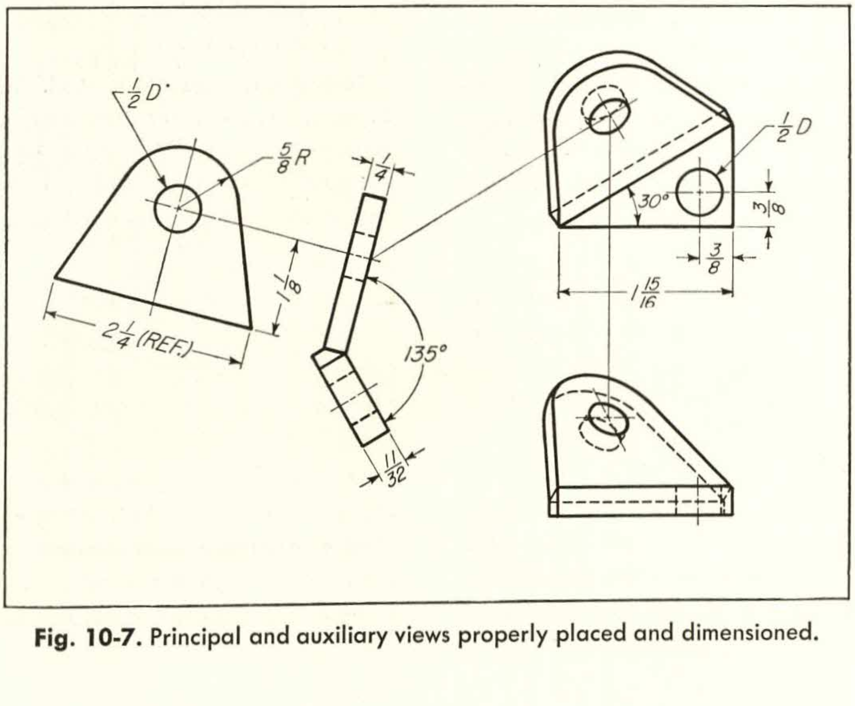
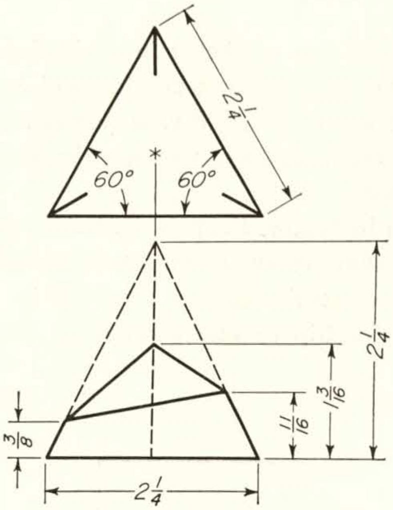


Fig. 10-7. Principal and auxiliary views properly placed and dimensioned.

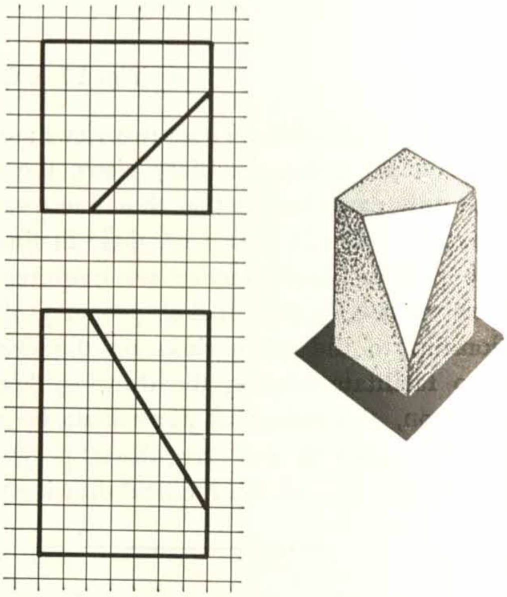
PROBLEMS

These problems have been selected to give the student an opportunity to apply the fundamental principles involved in projecting and dimensioning true-shape secondary auxiliary views. Although in practice, when a true-shape view of an oblique surface is required, it is customary to show in the primary auxiliary only the edge view of the oblique plane and in the secondary auxiliary only the shape and details of the oblique surface, it is suggested that the entire object be shown for at least one problem to permit the student to gain experience in auxiliary-view-projection procedure. A thumbnail sketch will aid in selecting and arranging the views on the sheet, and numbering the points of the planes will avoid confusion in projecting them.

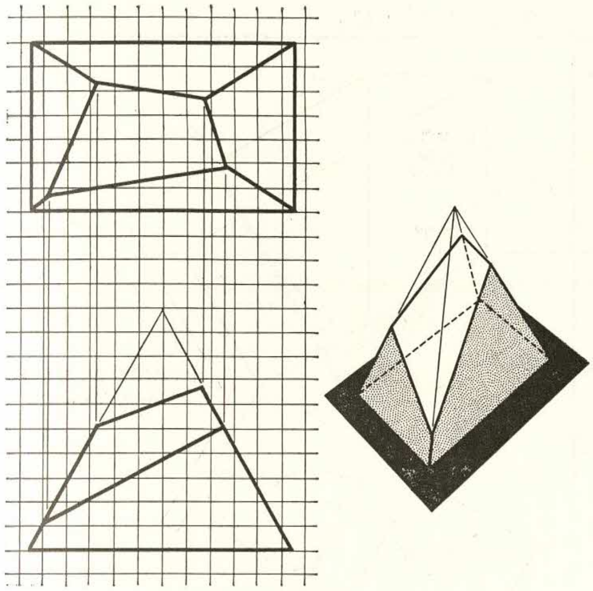
In a number of the problems given here, the dimensions used for locating the views on the sheet should also be omitted from your final drawing. Problems 10-1 to 10-7 can be shown on 8½- by 11-in. sheets, while Probs. 10-8 to 10-12 should be drawn on 11- by 17-in. sheets. A simple detail title should be located where convenient.



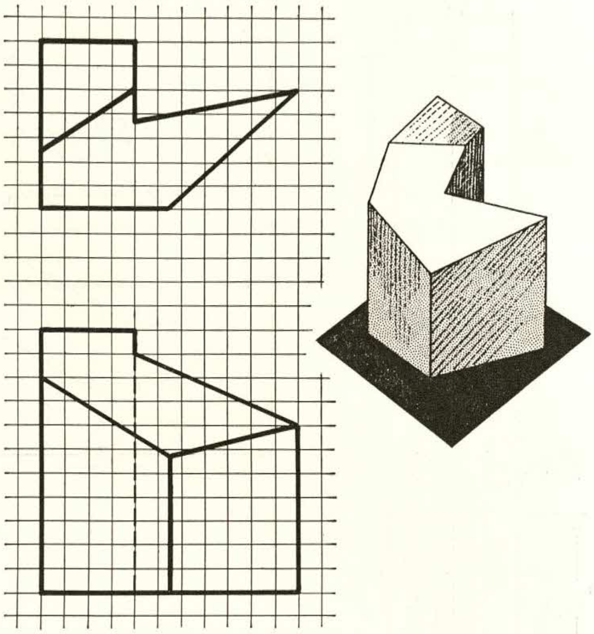
10-1. Truncated triangular pyramid, wood. Reproduce the front view, and complete the top view. Show the top oblique surface as a line projection in the primary auxiliary and in its true shape in the secondary auxiliary. Do not dimension. (Time. 1 hr.)



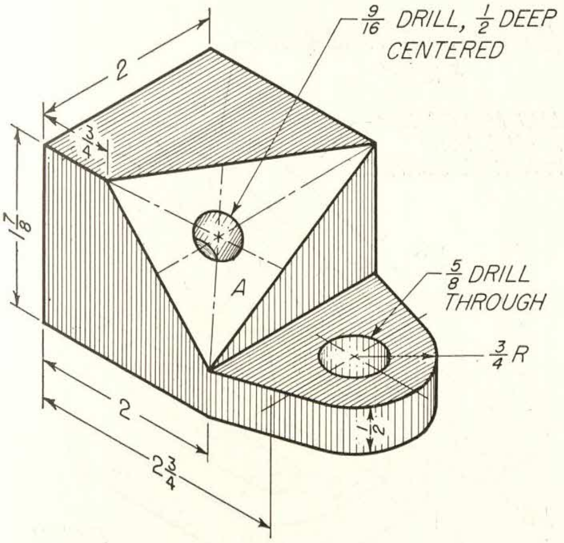
10-2. Angle gage block, steel. Assuming the squares to be ¼ in., reproduce the two given views. Show the appearance of the block in the view illustrating the oblique surface as an edge and in the view showing the surface in its true shape. Do not dimension. (Time. 1½ hr.)



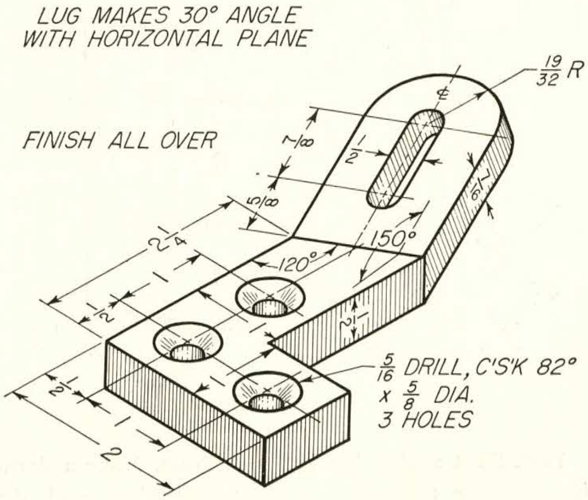
10-3. Truncated rectangular pyramid, wood. Using the ¼-in. squares, reproduce the top and front views, and add auxiliary views that show the top oblique surface as an edge and in its true shape. Do not dimension. (Time. 1½ hr.)



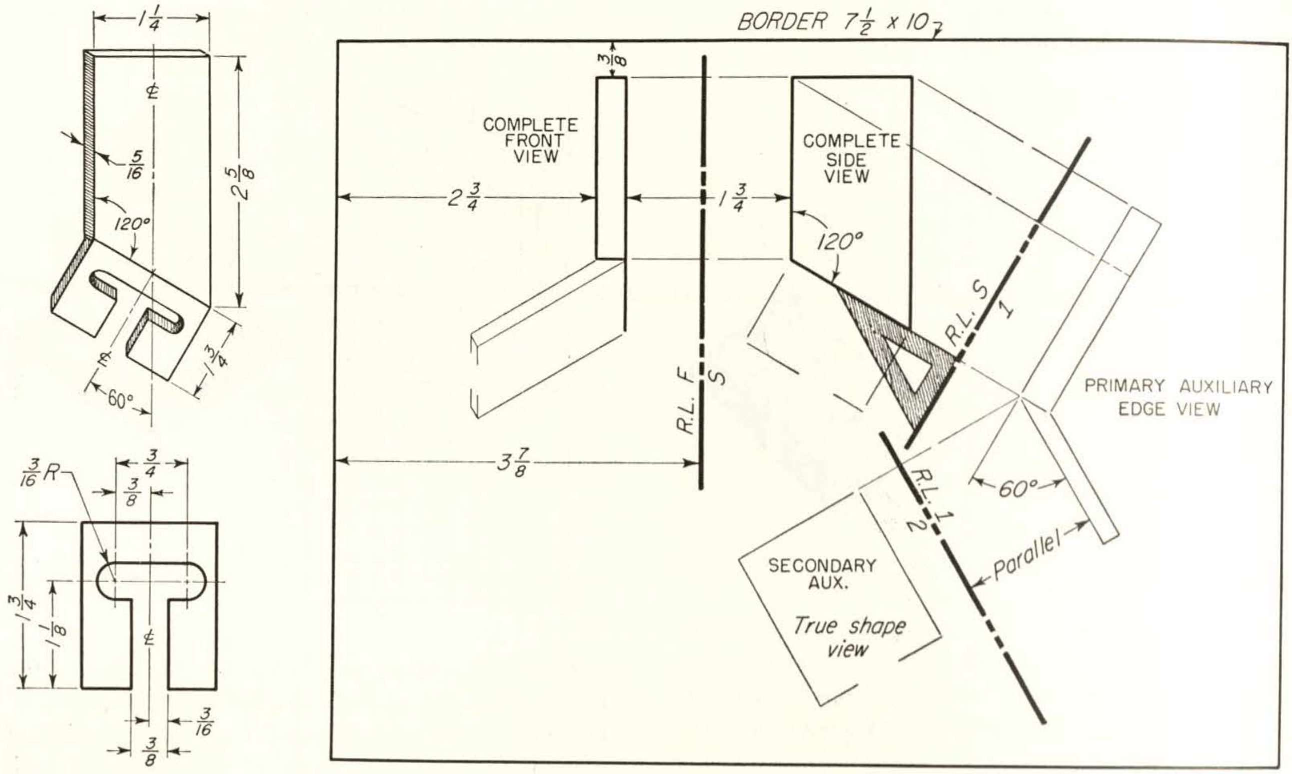
10-4. Wedge block, cast iron. Using the ¼-in. squares, redraw the front and top views, and show the auxiliaries that present the edge view and the true-shape view of the top oblique surface. (Whenever an oblique plane is shown bounded by more than three sides, or edges, extreme accuracy in drawing is required or the plane may not project as an edge in the primary auxiliary view.) Do not dimension. (Time. 1½ hr.)



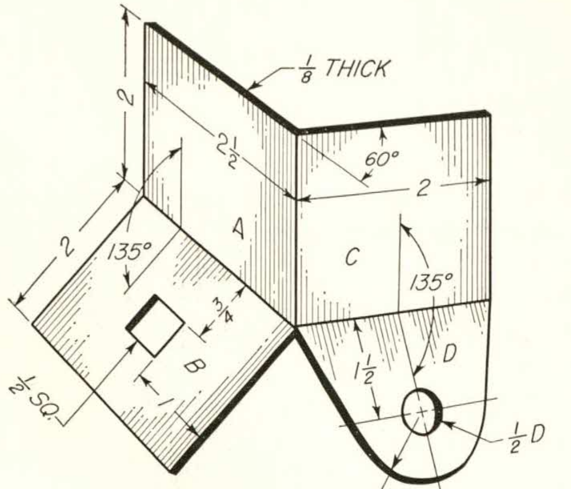
10-5. Corner rod anchor and guide, cast iron. Show two complete principal views. Draw a primary auxiliary that shows only the oblique surface *A* as an edge and a secondary auxiliary that shows only the oblique surface with its hole. Dimension completely. (Time. 2½ hr.)



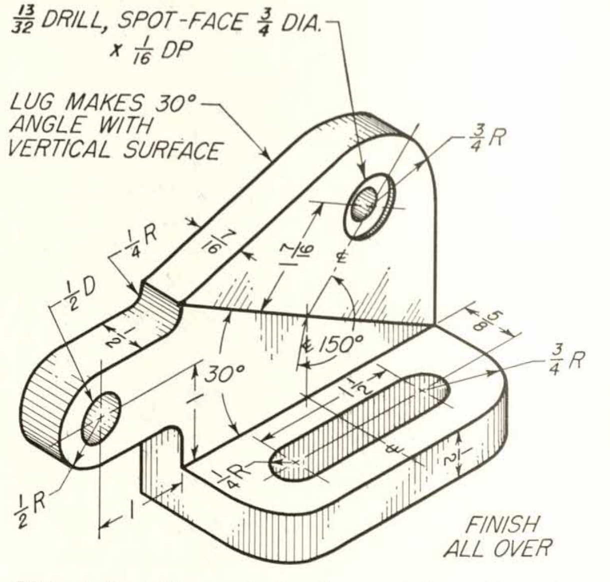
10-6. Corner brace guide, brass. Draw two complete principal views. Show only the oblique lug with its slot in the edge and true-shape auxiliary views. Dimension completely. (Time. 3 hr.)



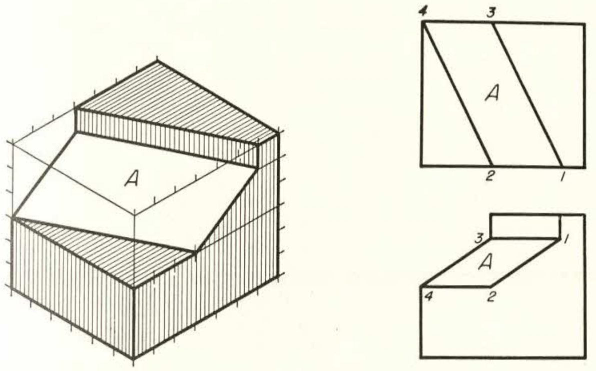
10-7. Angular corner bracket, steel. Using the layout shown and the pictorial and true-shape orthographic at the left, make a suitable, completely dimensioned working drawing. The front, side, and primary auxiliary must be complete views. In the secondary auxiliary, show only the true shape of the oblique lug. Omit reference lines and dimensions that locate views. (Time. 3 hr.)

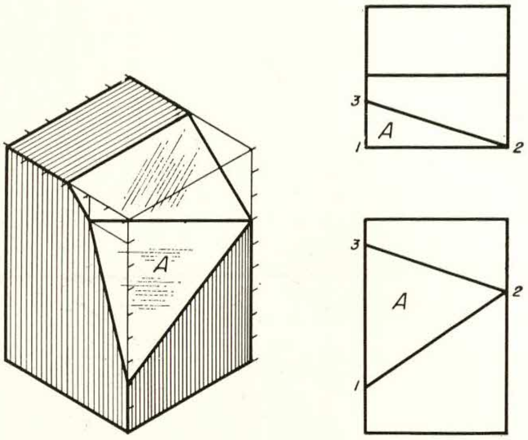


10-8. Strut anchor bracket, aluminum. Make a drawing showing two complete principal views and the necessary primary and secondary auxiliaries to permit proper dimensioning of the surfaces and the holes in the views where they are seen in their true shapes. Follow strictly the rules of projection. (Time. 3 hr.)

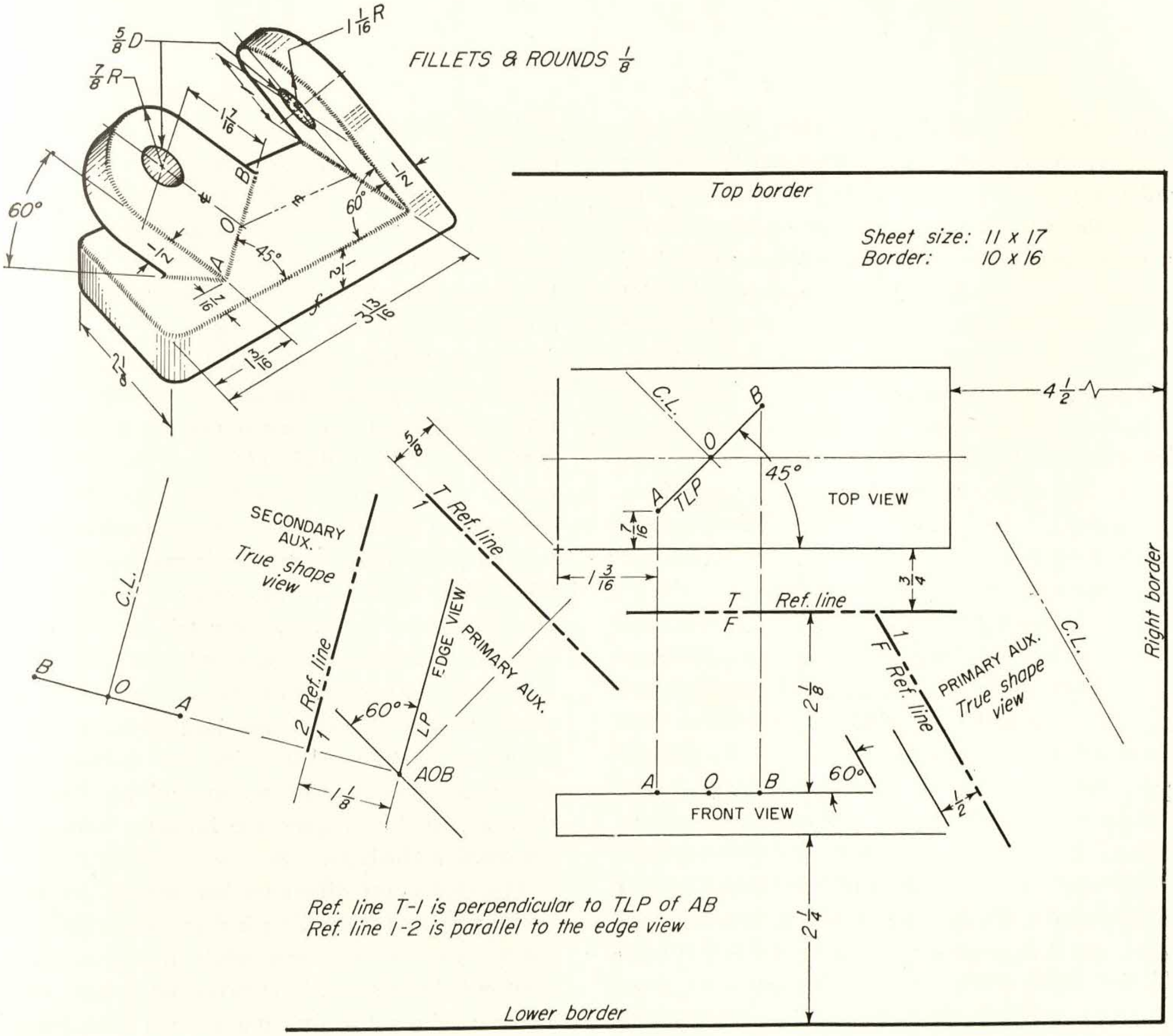

13/32 DRILL, SPOT-FACE 3/4 DIA. x 1/16 DP
LUG MAKES 30° ANGLE WITH VERTICAL SURFACE
3/4 R
1/4 R
7/16
7/16
℄
1/2 D
1/2
℄ 150°
30°
5/8
3/4 R
1 1/2
1/4 R
1/2
1/2 R
1
FINISH ALL OVER

10-9. Adjustable angle bracket, cast iron. Draw two complete principal views. Show only the lug with the spot-faced hole in the primary and secondary auxiliaries. Dimension the drawing completely. (Time. 4 hr.)





10-10 and 10-11. Angle blocks, steel. Using the ¼-in. divisions, reproduce the given front and top views. Draw the view that shows surface *A* as an edge and the view that shows it in its true shape. Do not dimension. (Time. 1 hr. for each problem.)



10-12. Cable anchor, cast iron. Using the pictorial at the left to obtain the dimensions of the object and the layout at the right for the location of the views and the reference lines on the sheet, complete the front and top views, and show the true shapes of both lugs with the holes in the proper auxiliary views. Omit dimensions locating views on the sheet, and dimension the drawing completely. (Time. 5 hr.)

Chapter 11

PICTORIAL DRAWING

In engineering-drafting procedure, it is often necessary to prepare drawings that can be read by individuals who lack the technical knowledge to enable them to read orthographic representations. In such cases, either *isometric* or *oblique* drawings are usually prepared. These are actually pictorial views drawn according to a number of well-defined principles that permit accurate size representation. The drawings may be scaled with a measuring stick, and the novice can read them with comparative ease. As a general rule, the isometric and oblique drawings are suitable only for relatively simple objects, since accurately scaled drawings can be made only when the constructional details are not complex.

11-1. Theory of isometric projection. An isometric *projection* of a rectangular solid such as a cube is obtained by revolving the cube through 45° about a vertical axis and tilting it forward so that the receding surfaces may be seen on the picture plane (see Fig. 11-1). It should be imagined that a body diagonal is passed through two extreme corners of the cube, which is then tipped forward toward the picture plane until the body diagonal is horizontal and appears as a point. The receding edges will then appear to make angles of 30° with the horizontal, while the vertical edges remain so.

In Fig. 11-1, the three heavy lines intersecting at point *O* are the *isometric axes.* The remaining lines outlining the isometric planes are parallel to these axes and are called *isometric lines.* The receding isometric axes make an angle of 120° with each other, an angle of 60° with the vertical axis, and angles of 30° with the horizontal. In the isometric-projection view, the lines of the cube are foreshortened and do not show in their true lengths, as can be noted by comparison with the orthographic view.

11-2. Isometric drawings. In making an isometric drawing, the principle of isometric projection is employed, but one important modification is made: *The lines of the object are drawn in their actual length, and the foreshortening effect is disregarded.* This means that an isometric drawing will be larger than an isometric projection, but it will still be in the same proportion (see Fig. 11-2). In commercial practice, isometric *drawings* (as opposed to isometric projections) are used almost exclusively because they can be prepared easily and the lengths of the lines may be scaled directly. It is important to keep in mind the difference between an isometric projection and an isometric drawing. In this chapter, the isometric drawing is discussed exclusively.

The significant difference between an isometric and a perspective drawing is that receding lines in the perspective converge, while in the isometric they remain parallel. The principal difference between an isometric drawing and an orthographic view lies in the fact that the orthographic view generally shows only one surface in a given view, while the isometric usually shows three or more.

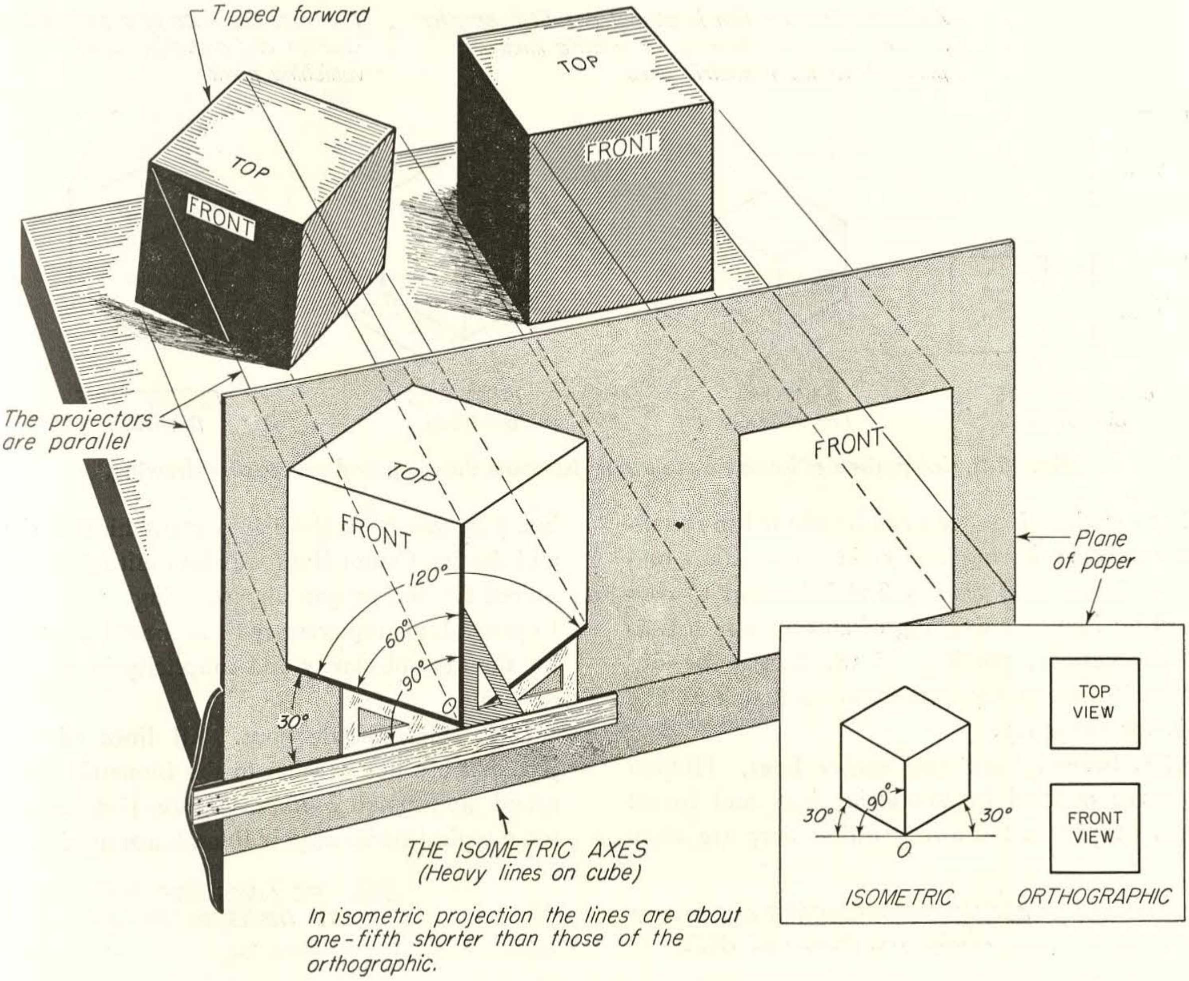

Tipped forward
TOP
FRONT
TOP
FRONT
The projectors are parallel
TOP
FRONT
120°
60°
90°
30°
O
FRONT
Plane of paper
TOP VIEW
FRONT VIEW
30°
90°
30°
O
ISOMETRIC
ORTHOGRAPHIC
THE ISOMETRIC AXES (Heavy lines on cube)
In isometric projection the lines are about one-fifth shorter than those of the orthographic.

Fig. 11-1. Theory of isometric projection.

11-3. Isometric drawing of a cube. The step-by-step procedure in making an isometric drawing of a cube is shown in Fig. 11-3. The principal axes are drawn first, and the actual lengths of the edges of the sides are scaled on them. The remaining edges are then drawn parallel to the principal axes.

11-4. Various positions of the isometric axes. The positions of the isometric axes may be varied to suit the needs of the draftsman or to present the usual appearance of the object to the observer. The angles between the axes should not be changed, however, even though their positions on the drawing sheet are varied (see Fig. 11-4).

11-5. Isometric drawing of a rectangular solid. The method employed in making an isometric drawing of a rectangular solid is similar to that used in drawing the cube (see Fig. 11-5).

To draw the isometric view, start with the vertical axis *OB* (Step I). Draw axis *OA* toward the left and axis *OC* toward the right to make an angle of 120° with each other and 30° angles with a horizontal line. In Step II, the actual height *OE* of $2\frac{1}{4}$ in. is laid off on the vertical axis *OB*. The actual length *OF* of 3 in. is laid off on axis *OC*, and the depth *OD* of $1\frac{1}{4}$ in. is measured off on axis *OA*. In Step III, points *G* and *H* are found by drawing lines through *E* parallel to the receding axes. These lines establish the heights *DG* and *FH*, which will be equal to the measured distance *OE*. In Step IV, lines are drawn through points *G* and *H*, parallel to the receding axes, to intersect at *J* and to complete the visible outline of the solid as seen in the final drawing.

All the lines of the rectangular solid are isometric lines, and direct measurements may be taken along any of them. The instruments used in making the drawing were the T square, the 30°-60° triangle, and the scale.

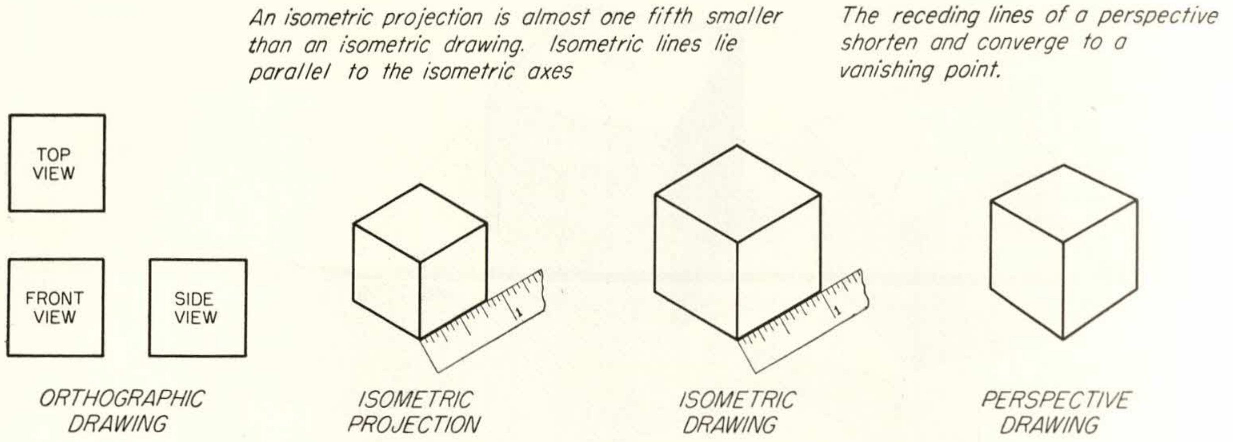

An isometric projection is almost one fifth smaller than an isometric drawing. Isometric lines lie parallel to the isometric axes
The receding lines of a perspective shorten and converge to a vanishing point.
TOP VIEW
FRONT VIEW
SIDE VIEW
ORTHOGRAPHIC DRAWING
ISOMETRIC PROJECTION
ISOMETRIC DRAWING
PERSPECTIVE DRAWING

Fig. 11-2. Comparison of isometric projection, isometric drawing, and perspective drawing.

Most engineering forms can be likened to rectangular solids appearing boxlike in construction, and the draftsman will usually find it helpful to construct an isometric drawing of an object in a boxlike framework, portions of which may be discarded if unnecessary (see the construction in Fig. 11-7, for example).

11-6. Hidden lines and center lines. Hidden lines are omitted in isometric views and in all forms of pictorial drawing unless they are absolutely necessary to show important hidden shapes and details. Center lines are also omitted unless required for the proper dimensioning of the object. In general, all unnecessary lines should be avoided for the sake of clarity and simplicity in the representation.

11-7. Nonisometric lines. All lines of an object that are not parallel to the isometric axes are called *nonisometric lines.* Figure 11-6 illustrates some typical nonisometric lines. Since nonisometric

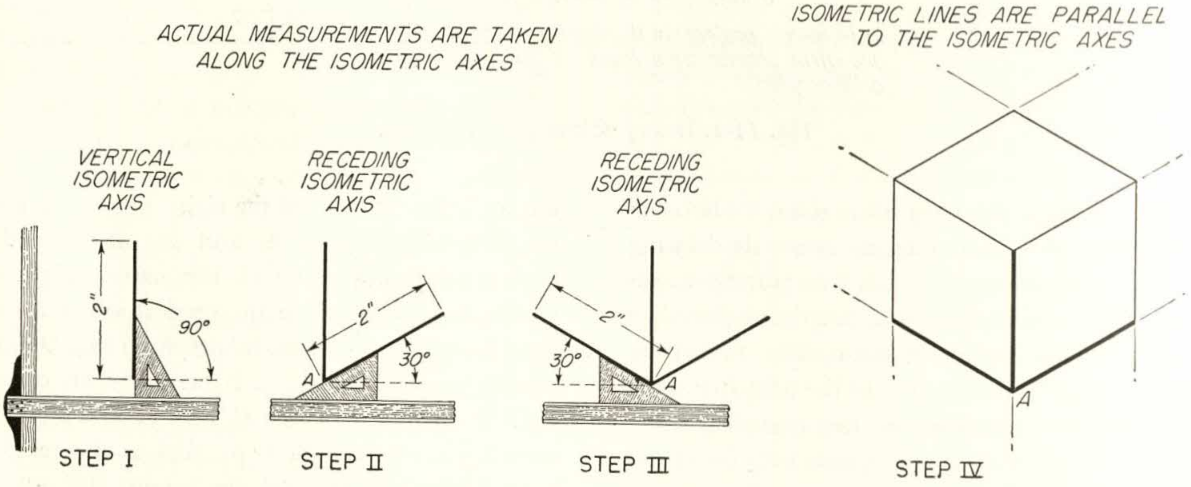


Fig. 11-3. Isometric drawing of a cube.

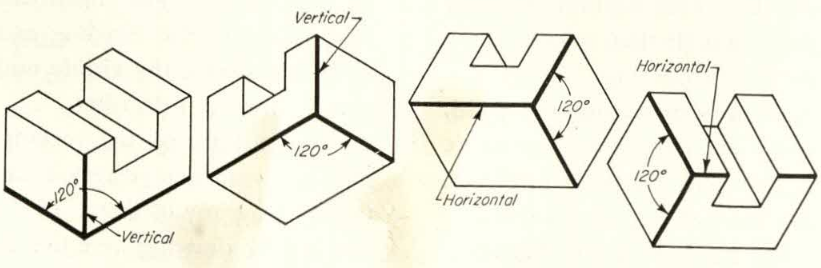


Fig. 11-4. Positions for isometric axes.

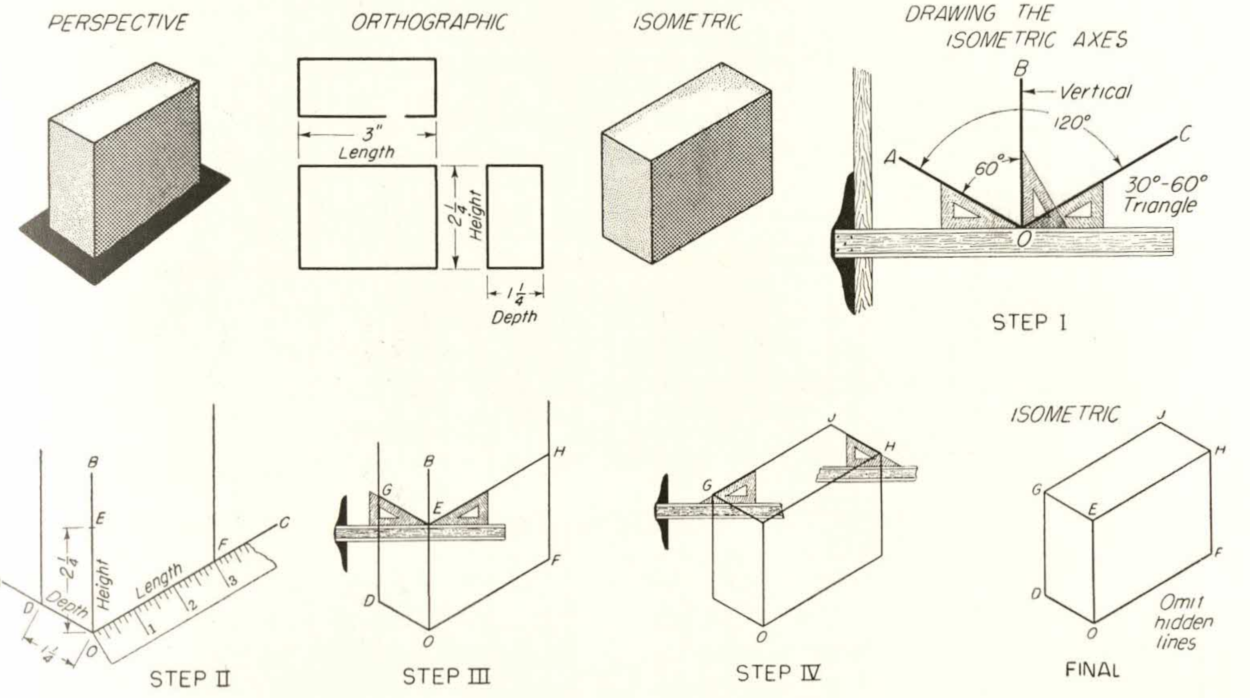


Fig. 11-5. Isometric drawing of a rectangular prism.

lines do not show in their true length in isometric views, measurements cannot be taken from them. In isometric drawings, isometric lines are the only ones from which measurements may be taken.

11-8. Isometric angles. The only angles that will appear in their true size in isometric drawings are those between lines shown on planes parallel to the surface of the drawing sheet. Referring again to Fig. 11-6, it can be noted that none of the angles on the different objects is on a surface parallel to the plane of the paper, and as a result they do not appear in their true size. To draw isometric angles formed by nonisometric lines, therefore, first construct an orthographic drawing of the object showing the true size of the angle with the true lengths of its sides.

The angle is transferred to the isometric by indicating its extreme points on vertical and horizontal lines (rectangular coordinates) in the orthographic views. With dividers, these points are then located on related isometrically projected lines in the isometric drawing to produce the desired angle.

11-9. Locating nonisometric lines and angles in isometric drawings. Figure 11-7*a* illustrates the method used in laying out nonisometric lines and angles in an isometric drawing. These lines and angles are first located on orthgraphic views drawn to the same scale as the isometric. They are then located on the isometric by projecting their significant intersections along isometric lines to their proper positions in the pictorial. For instance, point *H* in the isometric framework in Step II is

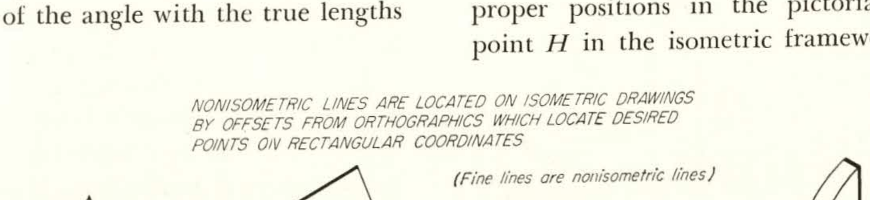

NONISOMETRIC LINES ARE LOCATED ON ISOMETRIC DRAWINGS BY OFFSETS FROM ORTHOGRAPHICS WHICH LOCATE DESIRED POINTS ON RECTANGULAR COORDINATES
(Fine lines are nonisometric lines)

Fig. 11-6. Nonisometric lines.

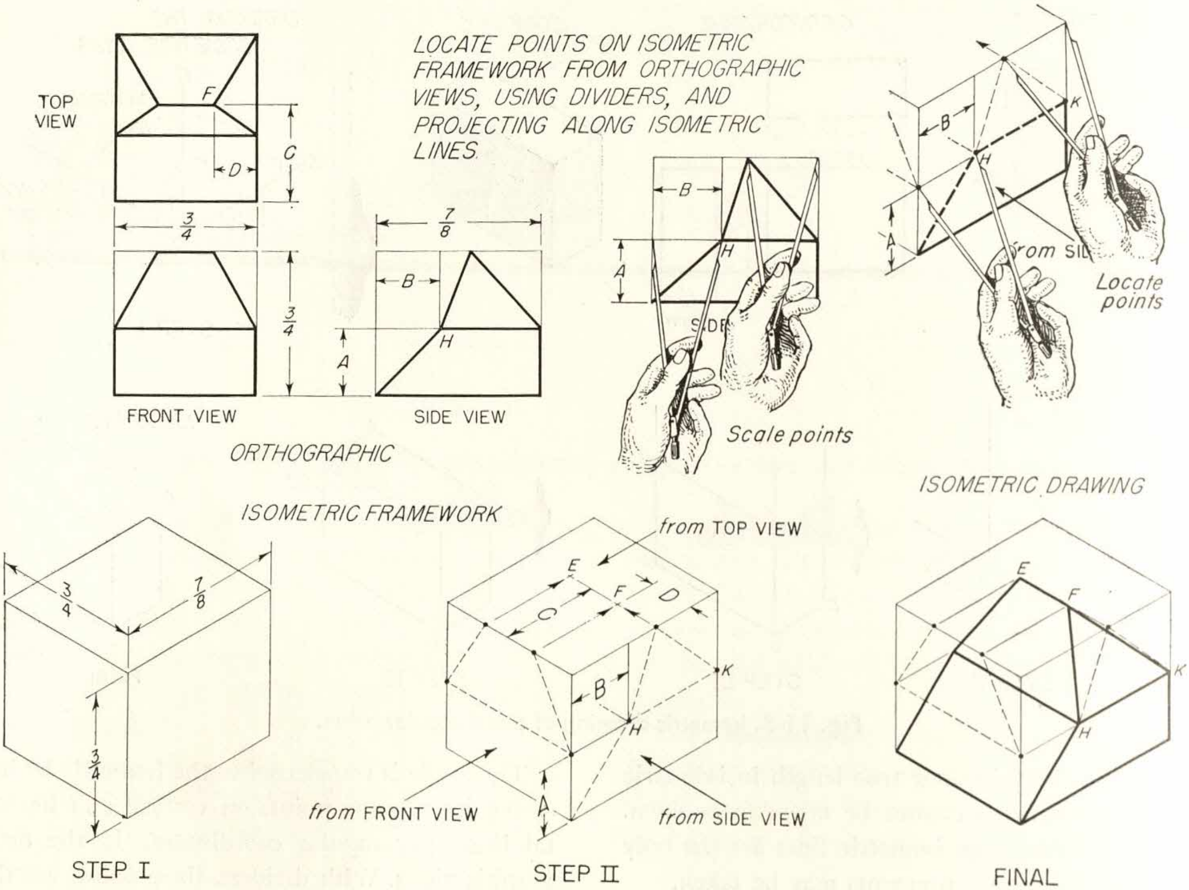


Fig. 11-7a. Locating angles and nonisometric lines.

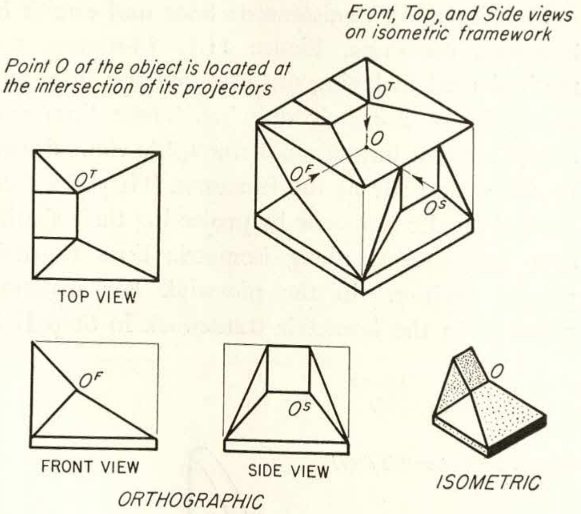

Front, Top, and Side views on isometric framework
Point O of the object is located at the intersection of its projectors
O^T
O
O^F
O^S
O^T
TOP VIEW
O^F
FRONT VIEW
O^S
SIDE VIEW
O
ORTHOGRAPHIC
ISOMETRIC

Fig. 11-7b. Using complete views to produce an isometric drawing.

located at the intersection of a pair of isometric coordinates lying on the right vertical receding plane. These isometric coordinates are the pictorial counterparts of the rectangular coordinates shown in the side view of the orthographic, where *H* also appears at their intersection. Distances *A* and *B*, scaled on the framework lines of both the orthographic and the isometric, serve to locate their respective coordinates. Point *F* is located in a like manner. The distances *C* and *D* are scaled from the orthographic top view and used to locate the isometric coordinates in the top receding plane of the isometric drawing. Their intersection denotes the location of point *F* in the pictorial.

There is still another approach to the locating of angles and nonisometric lines in isometric drawings that can be used advantageously if the object lends itself to a preliminary boxlike construction. If the orthographic views are constructed isometrically on their related faces on the isometric framework, the required points on the object may be found at the intersection of their isometric projectors. This procedure is shown in Fig. 11-7*b*.

The drawing of irregular curves is handled in the same manner (see Fig. 11-8). The true shape of the curve is first drawn orthographically. Then

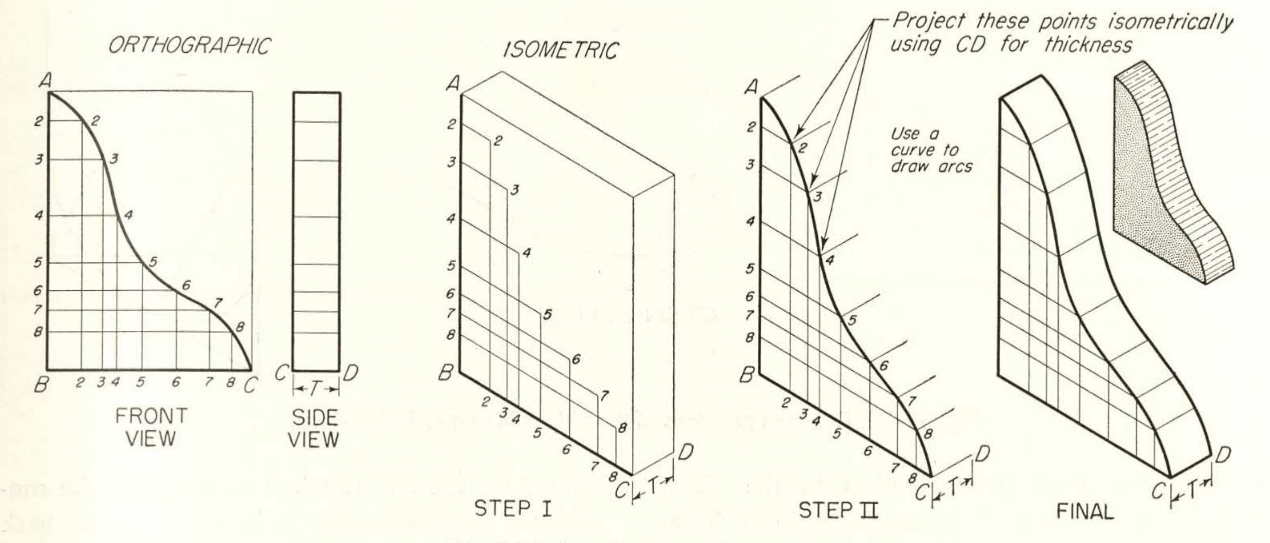


Fig. 11-8. Drawing irregular curves.

mark off any convenient number of points on the curve, say eight, and draw lines vertically and horizontally through these points. These lines are the rectangular coordinates of the points. The rectangular coordinates are then transferred to their proper positions on the isometric planes. For example, in Fig. 11-8 the distance *A*-2 along *AB* in the orthographic view is transferred to *AB* in the isometric drawing; *B*-2 along *BC* in the orthographic is transferred to *BC* in the isometric. The isometric lines drawn through these points will intersect at point 2 on the curve. All other points on the curve are secured in the same manner, and the points are connected to form the finished curve.

11-10. Drawing the circle in isometric. The circle rarely appears in its true shape in isometric drawings. Usually, a circle is located on one of the isometric planes, where it takes the shape of an ellipse. The manner in which such circles are drawn is shown in Fig. 11-9. In Step I, lay out an isometric square in the required position, making the sides *AB, BC, CD,* and *AD* equal in length to the diameter of the circle. In Step II, locate the points *E, F, G,* and *H* at the midpoints of the sides.

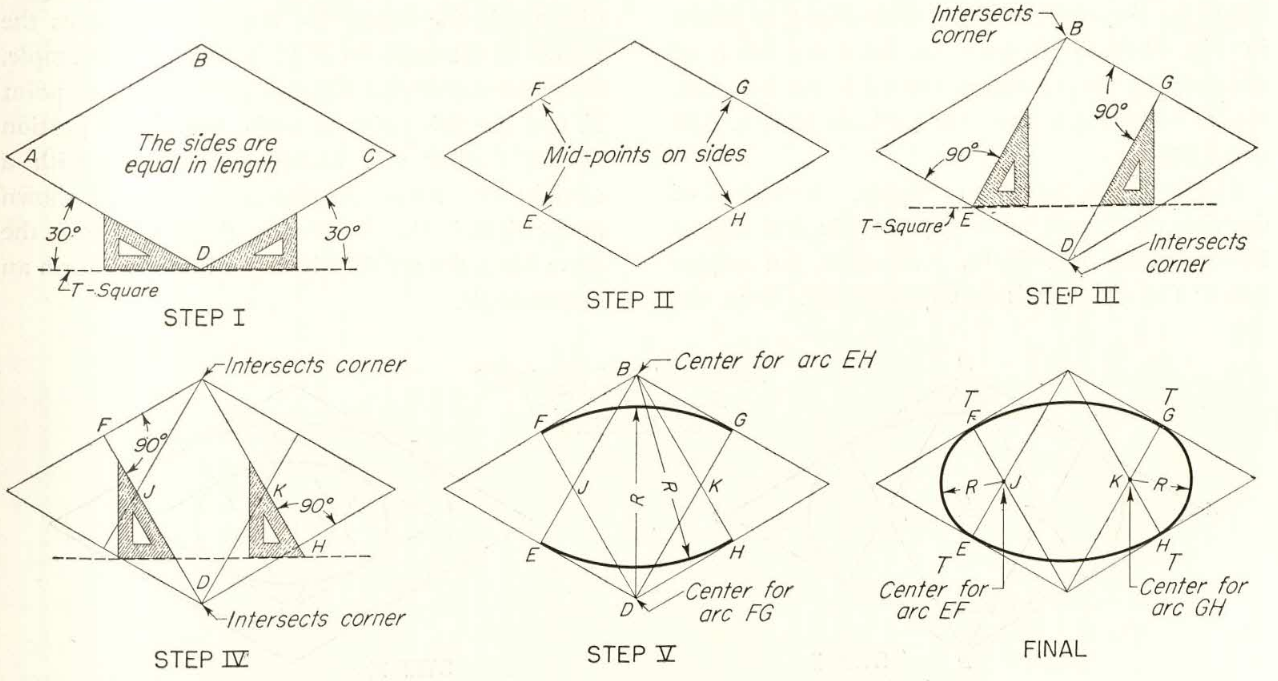


Fig. 11-9. Drawing the circle as an ellipse on the isometric plane.

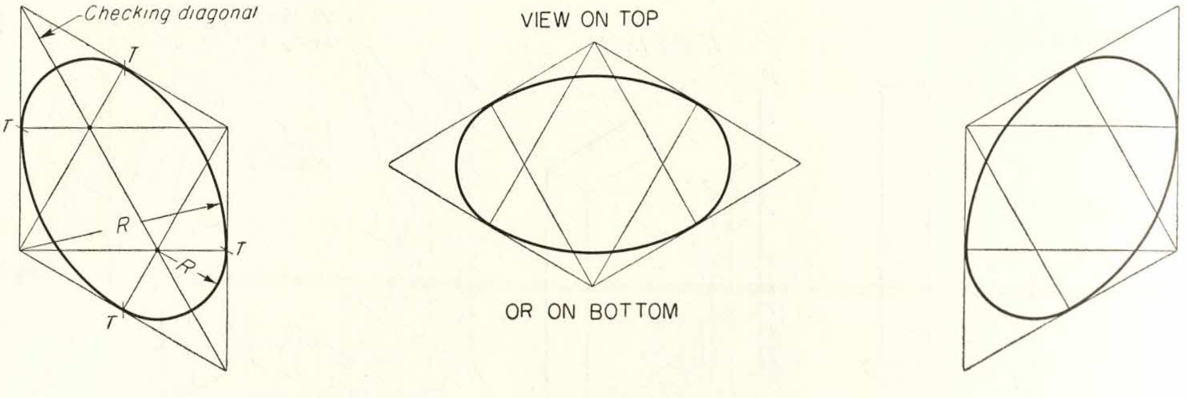


Fig. 11-10. Common positions of the ellipse in isometric drawings.

In Step III, erect perpendiculars to the sides through these points. If the work has been done accurately, the perpendiculars will intersect the opposite corners *B* and *D*. Follow the remaining steps as shown to complete the drawing. Note particularly the manner in which the instruments are used in the sequence of operations illustrated.

Figure 11-10 shows the representation of circles as ellipses in isometric squares on the planes most often encountered in isometric drawing. A diagonal passing through the far corners of the isometric squares should pass through the centers for the small arcs.

11-11. Concentric circles in isometric drawings. When concentric circles are to be shown on an isometric plane, a complete set of centers must be found for the construction of each ellipse, as shown in Fig. 11-11. This must be done regardless of whether the ellipses are produced in an isometric square or by the four-center methods of Secs. 5-26 and 5-28.

11-12. Shafts, holes, and tapers. A method of showing shafts and holes in isometric drawings is illustrated in Fig. 11-12. Note that the ellipse nearer the observer is first constructed. Then the centers for the arcs required to complete the construction of the farther ellipse are moved back parallel to the isometric axis of the cylinder a distance equal to the length of the shaft or the depth of the hole. These newly located centers are used to strike the visible portions of the arcs necessary to complete the drawing of the shaft or hole.

The manner in which tapers are constructed in isometric drawings is illustrated in Fig. 11-13. Note that the length is measured along the axis.

11-13. Circle arcs. The procedure followed in the construction of rounded forms and corners is shown in Fig. 11-14. Measure the radius of the arc along the sides of the angle from their point of intersection *O*. Erect perpendiculars to the sides at points *A* and *B*. The intersection *X* of the perpendiculars is the center for the arc that forms the round. If the material is $\frac{3}{8}$ in. thick, for example, move the center that distance isometrically to point *Y*, and use this point to strike the visible portion of the farther arc. Finish the contour with a straight line drawn tangent to the arcs. As shown at the right in the illustration, the procedure is the same when the arc falls between lines that form an obtuse angle.

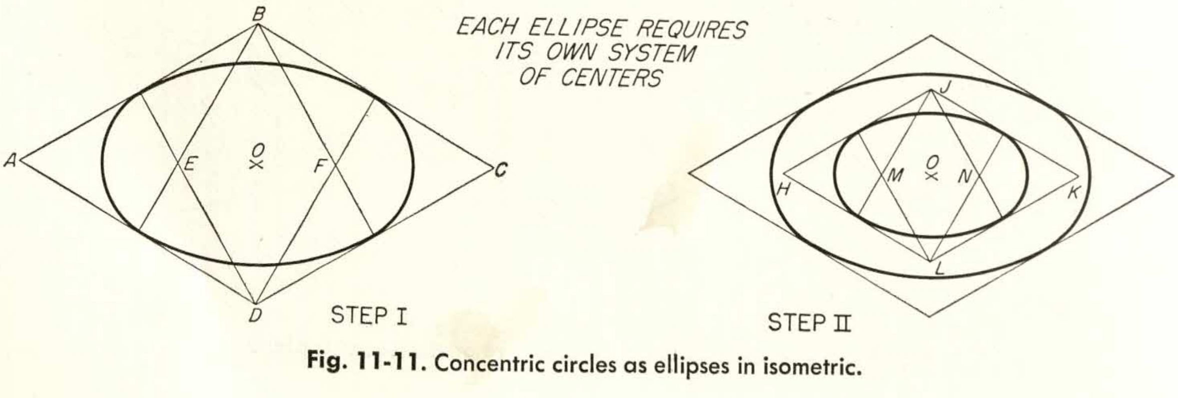


Fig. 11-11. Concentric circles as ellipses in isometric.

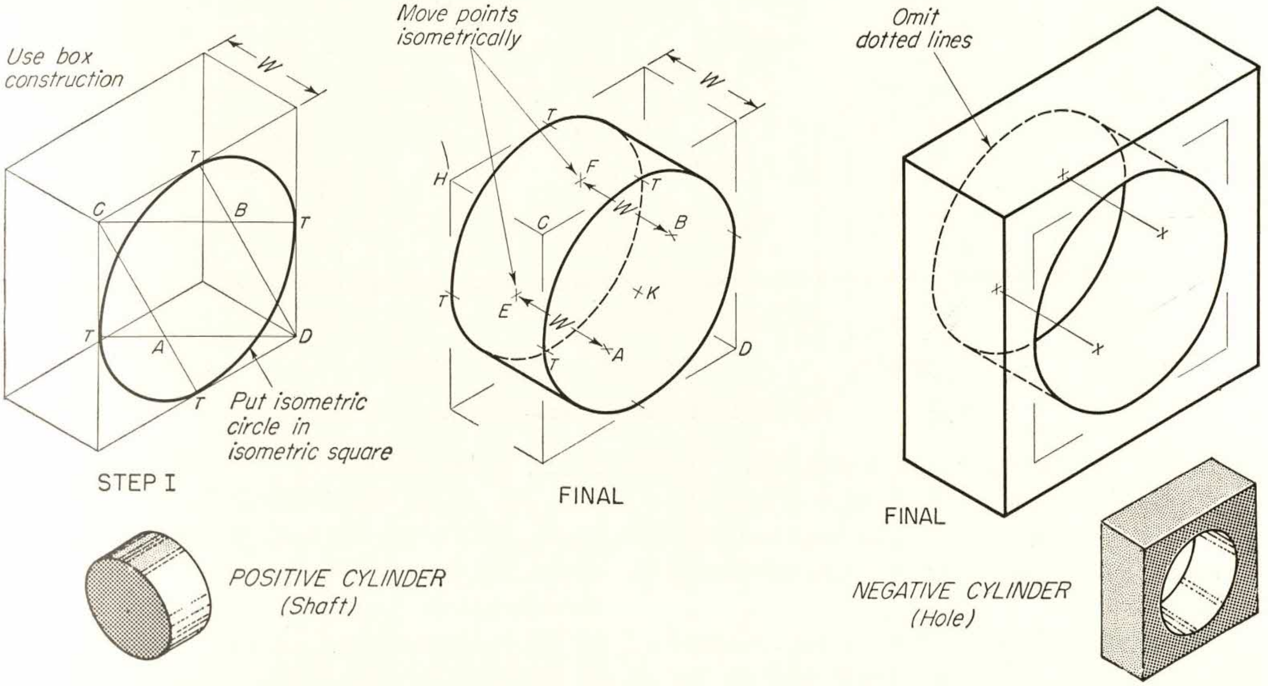


Fig. 11-12. Drawing of shafts and holes in isometric.

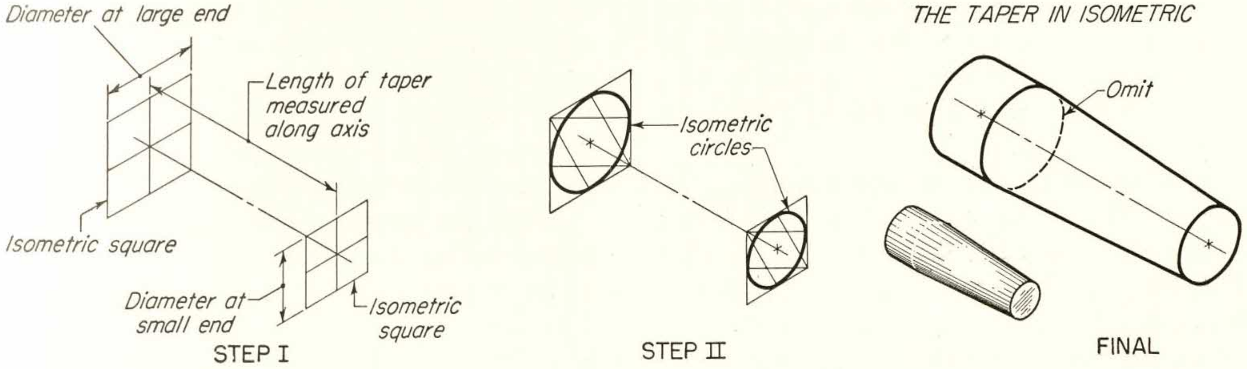


Fig. 11-13. Drawing the taper in isometric.

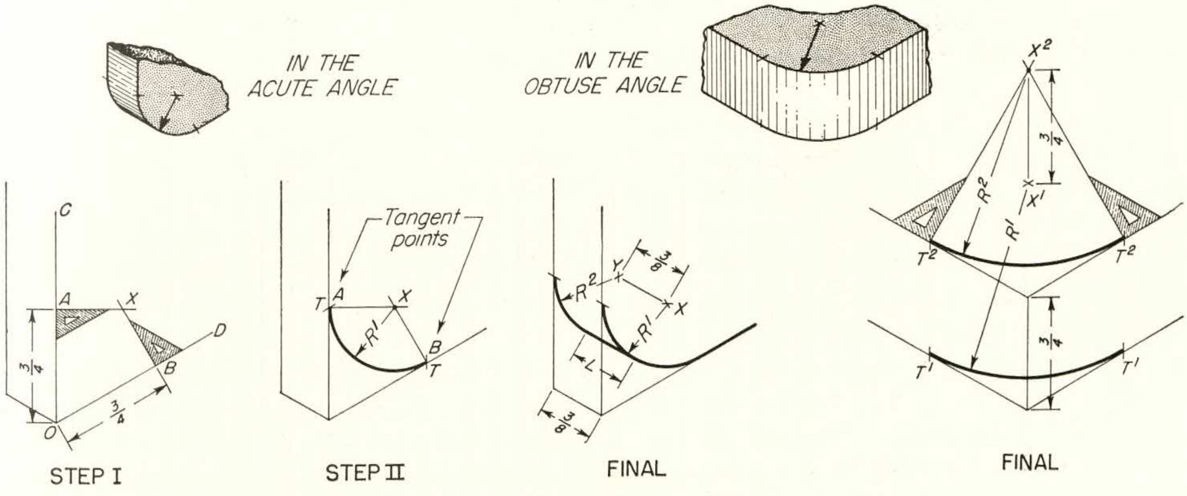


Fig. 11-14. Circle arcs for rounding corners.

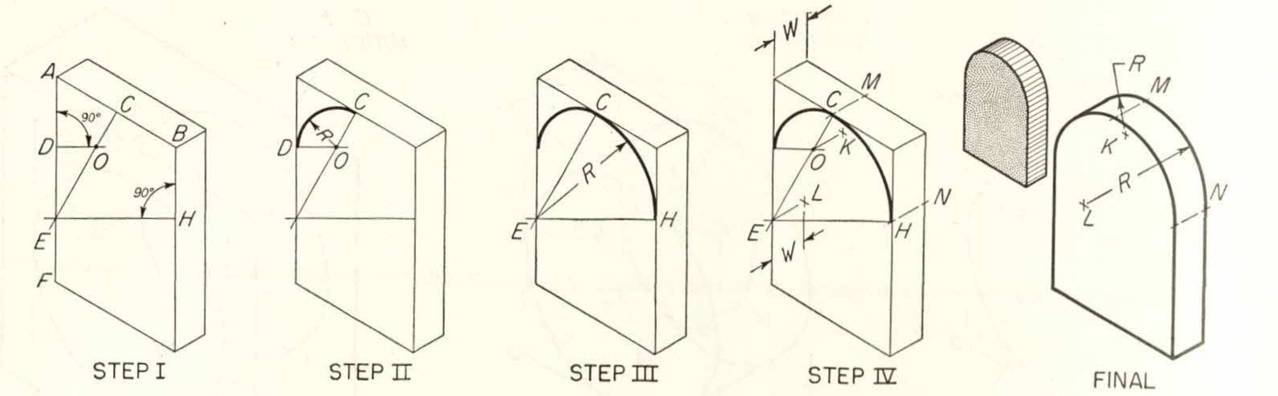


Fig. 11-15. Pieces with round ends.

If a part ends in a complete round, follow the steps pictured in Fig. 11-15. Note that only the centers for the required small and large arcs need be found. The centers are then moved isometrically to draw the farthermost arcs.

The procedure for drawing a slot with rounded ends is shown in Fig. 11-16. Begin with an isometric rectangle, the height and width of whose sides are equal to the over-all dimensions of the slot. Construct half ellipses at each end of the rectangle. Then move the centers isometrically to draw the portions of the partially visible arcs. Complete the drawing of the slot by joining the arcs with straight lines.

11-14. The ellipse in a nonisometric plane. To draw an ellipse in a nonisometric plane, it is first necessary to draw a true-shape orthographic view of the ellipse, as shown in the auxiliary view of Fig. 11-17*a*. The rectangular coordinates intersecting at significant points on the ellipse are found (see method described in Sec. 11-9) and are projected back to the orthographic side view. These coordinates are then placed on the framework of the isometric to locate the ellipse on the inclined surface in the pictorial.

In Fig. 11-17*b*, the isometric framework is first drawn, after which the conjugate diameters of the ellipse are located. To find the long and short diameters of the four-center ellipse that was drawn on the inclined surface, use the method described in Sec. 5-26. In Fig. 11-17*c*, the isometric framework with its inclined surface and the isometric circle in the base are first drawn, after which points on the circle are projected vertically, then isometrically from the circle to the side of the framework, next, to the edge and then across the inclined surface. The intersections of the rectangular coordinates thus projected locate points that outline the ellipse on the inclined surface.

11-15. The sphere in isometric. The isometric representation of a sphere consists of the envelope of all its great circles. The drawing procedure as illustrated in Fig. 11-18 is as follows: Draw the given diameter of the sphere located within an isometric square. Construct an isometric circle within this square. The long diameter of the ellipse thus formed is the diameter of the desired isometric sphere.

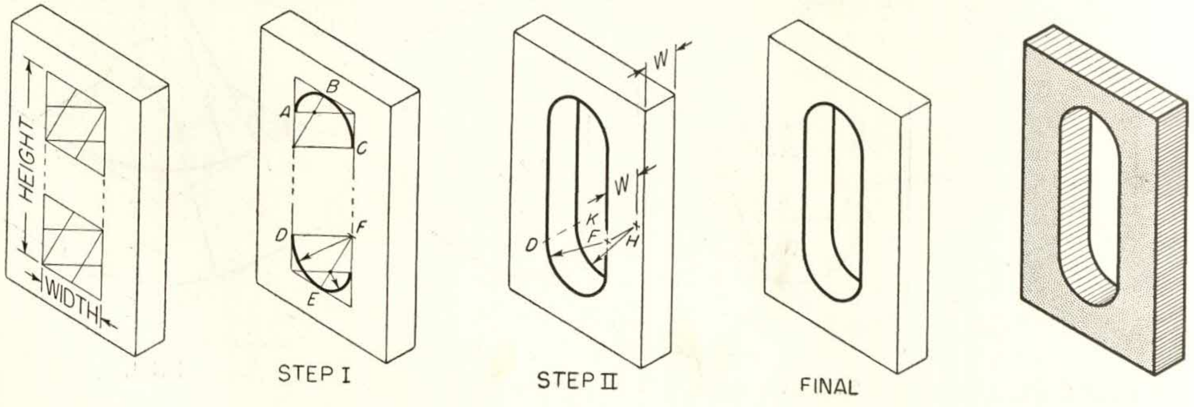


Fig. 11-16. Round-end slots.

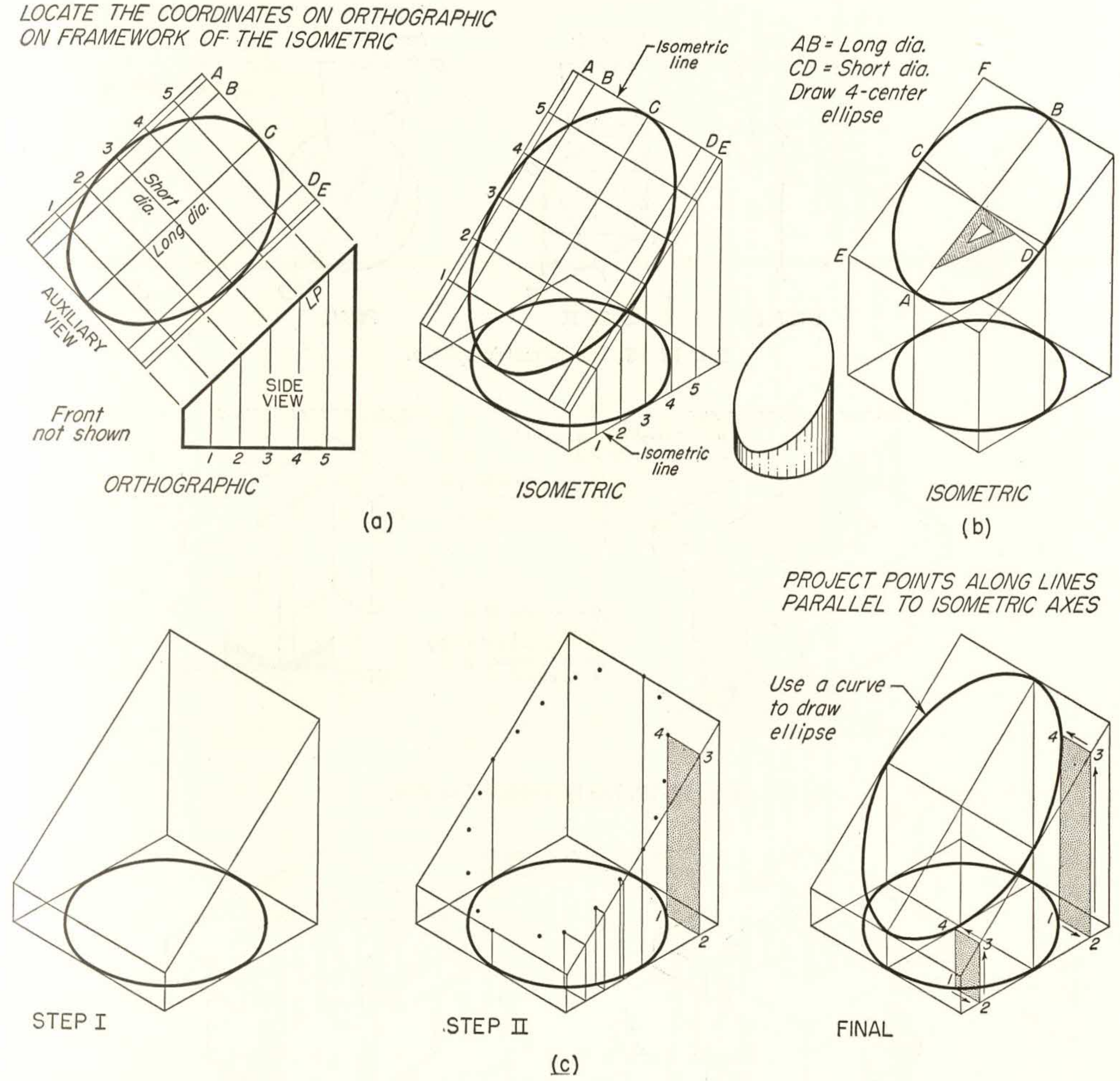


Fig. 11-17. Drawing the ellipse on a nonisometric plane.

11-16. Isometric full section. Isometric section views may be drawn to show unusual details of interior construction (see Fig. 11-19). The imaginary cutting plane for a full section is passed through the center of the object parallel to one of the receding isometric axes. The revealed interior features are completed according to the principles of isometric drawing. The section lining for the cut portion may be drawn at any appropriate angle, but care should be taken to make sure that it does not run parallel with the principal lines of the cut contours of the object. As a general rule, a 60° slope for the section lining will be found satisfactory on most isometric-section drawings.

11-17. Isometric half section. The imaginary cutting planes for the isometric half section are passed parallel to the receding isometric axes and intersect the center line (see Fig. 11-20).

11-18. Broken-out sections. The imaginary cutting planes for showing broken-out sections may be passed at any desired position parallel to the isometric axes (see Fig. 11-21). The cutting planes should pass through the axis of holes, shafts, and similar features if a true cross section of their cut contours is desired.

11-19. Isometric dimensioning. Basically, isometric drawings are dimensioned according to the same general rules followed in orthographic dimen-

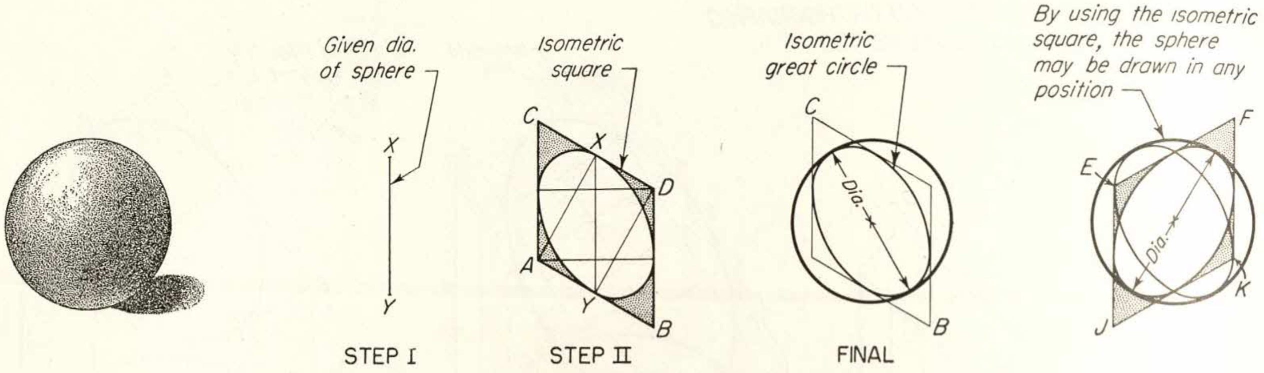


Fig. 11-18. The isometric sphere.

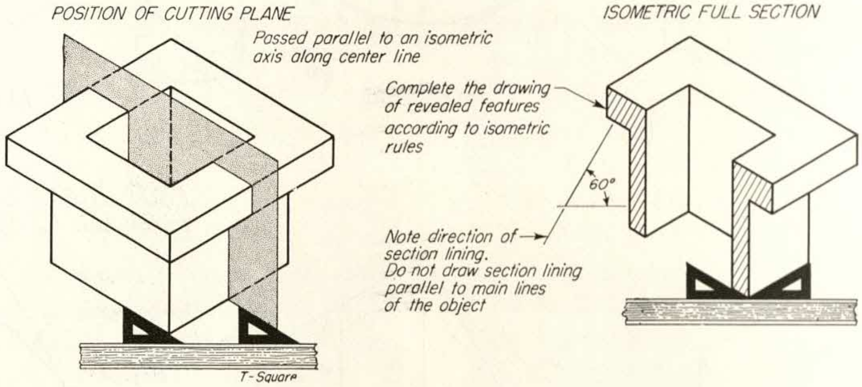

POSITION OF CUTTING PLANE
Passed parallel to an isometric axis along center line
T-Square
ISOMETRIC FULL SECTION
Complete the drawing of revealed features according to isometric rules
60°
Note direction of section lining.
Do not draw section lining parallel to main lines of the object

Fig. 11-19. The isometric full section.

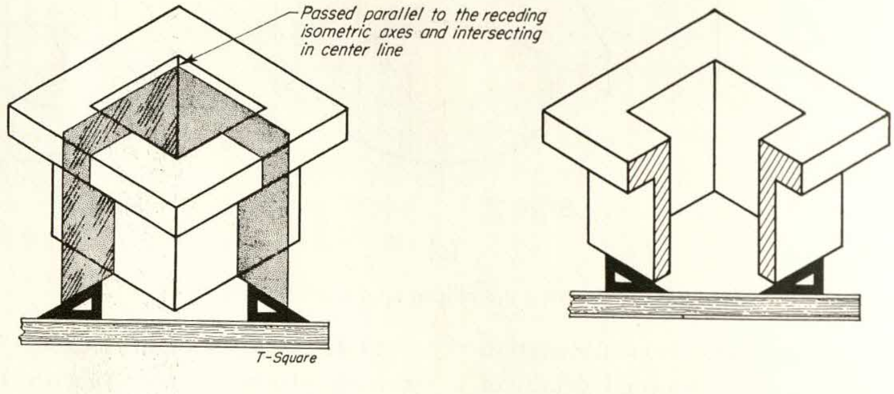

Passed parallel to the receding isometric axes and intersecting in center line
T-Square

Fig. 11-20. The isometric half section.

sioning. The dimensions given should be clear and should provide all the information necessary for the fabrication of the part. As shown in Fig. 11-22, in isometric drawings the dimension and extension lines, the slope and guide lines, and the dimension figures are all drawn parallel to the isometric axes. Notes, on the other hand, should lie in the plane of the paper. Whenever possible, dimensions should be placed to read horizontally or from the right. This rule may be violated, however, if it leads to inverted, or nearly inverted, lettering.

11-20. Theory of oblique projection. The simplest type of pictorial to make is the oblique drawing. Figure 11-23 compares an orthographic representation of a cube whose nearest face is parallel to the picture plane, or surface of the paper, with an oblique projection appearing on the same surface. While only one surface may be seen

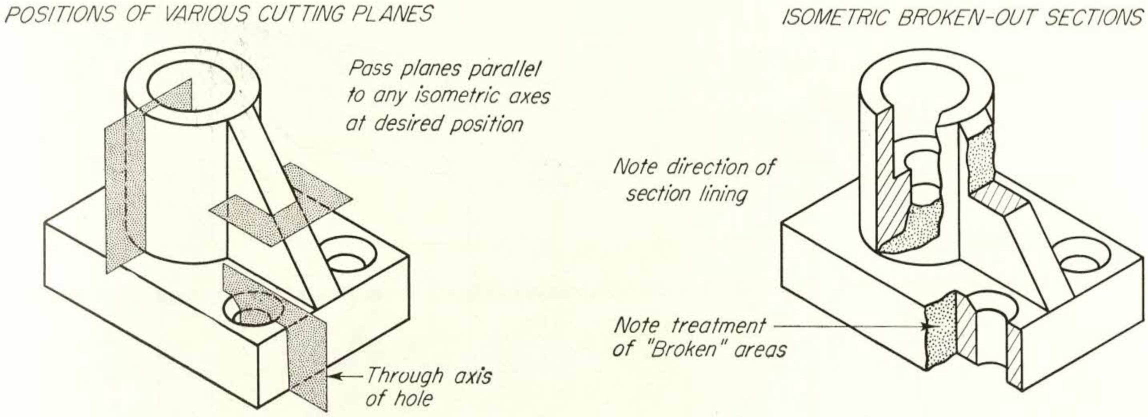

POSITIONS OF VARIOUS CUTTING PLANES
Pass planes parallel to any isometric axes at desired position
Through axis of hole
ISOMETRIC BROKEN-OUT SECTIONS
Note direction of section lining
Note treatment of "Broken" areas

Fig. 11-21. Isometric broken-out sections.

in a given orthographic view, an oblique view shows the front and two receding planes in one projection. The front face of the cube is seen in its true size and shape in both drawings. The projectors of the orthographic image are parallel to each other and are perpendicular to the picture plane. The projectors of the oblique view are also parallel to each other but are not perpendicular to the picture plane. In this case, they make an angle of less than 90° with the drawing surface, thus indicating that the observer is looking toward and down at the cube. Since the projectors are parallel, the nonreceding horizontal lines of the cube will appear horizontal and parallel in the oblique view, the verticals will appear vertical and parallel, and the receding lines will appear parallel and make the same angles with any horizontal line or any vertical line. An immediate advantage over isometric projection is noticeable in that one face of an object—the one parallel to the surface of the drawing sheet—may always be represented in its true size and shape.

11-21. The oblique axes. The oblique axes are three lines, two of which are always perpendicular to each other and rest in the plane of the paper, while the third is a receding line that may make any convenient angle with a horizontal line. The angle selected should be one that permits showing the details of the desired receding surface as clearly as necessary (see Fig. 11-24). The posi-

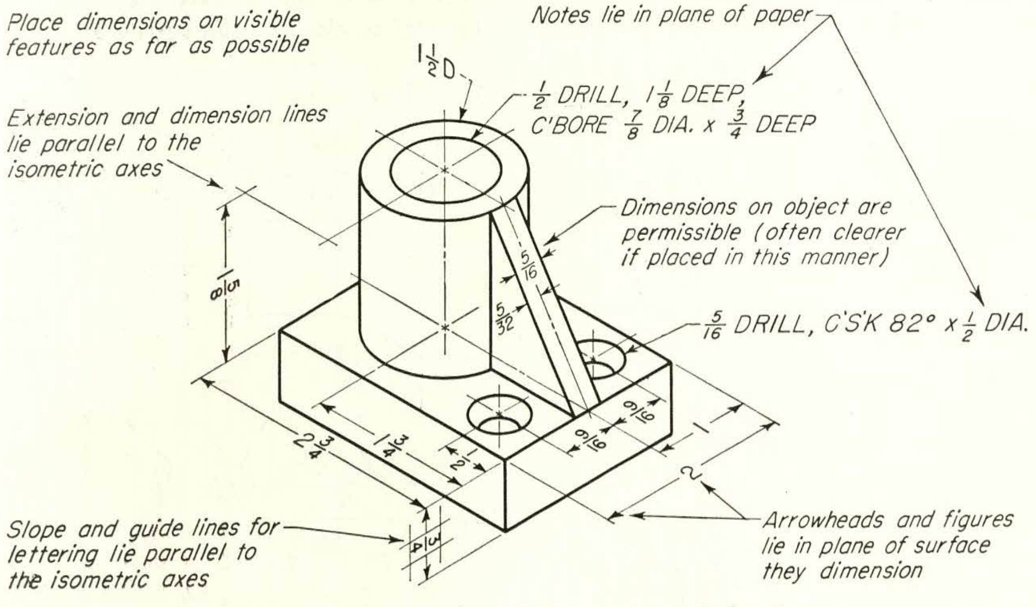

Place dimensions on visible features as far as possible
Extension and dimension lines lie parallel to the isometric axes
Slope and guide lines for lettering lie parallel to the isometric axes
Notes lie in plane of paper
1½ D
½ DRILL, 1⅛ DEEP, C'BORE 7/8 DIA. x 3/4 DEEP
Dimensions on object are permissible (often clearer if placed in this manner)
5/16
5/32
5/8
5/16 DRILL, C'SK 82° x ½ DIA.
2¾
1¾
½
9/16
9/16
1
2
3/4
Arrowheads and figures lie in plane of surface they dimension

Fig. 11-22. Rules for dimensioning an isometric drawing.

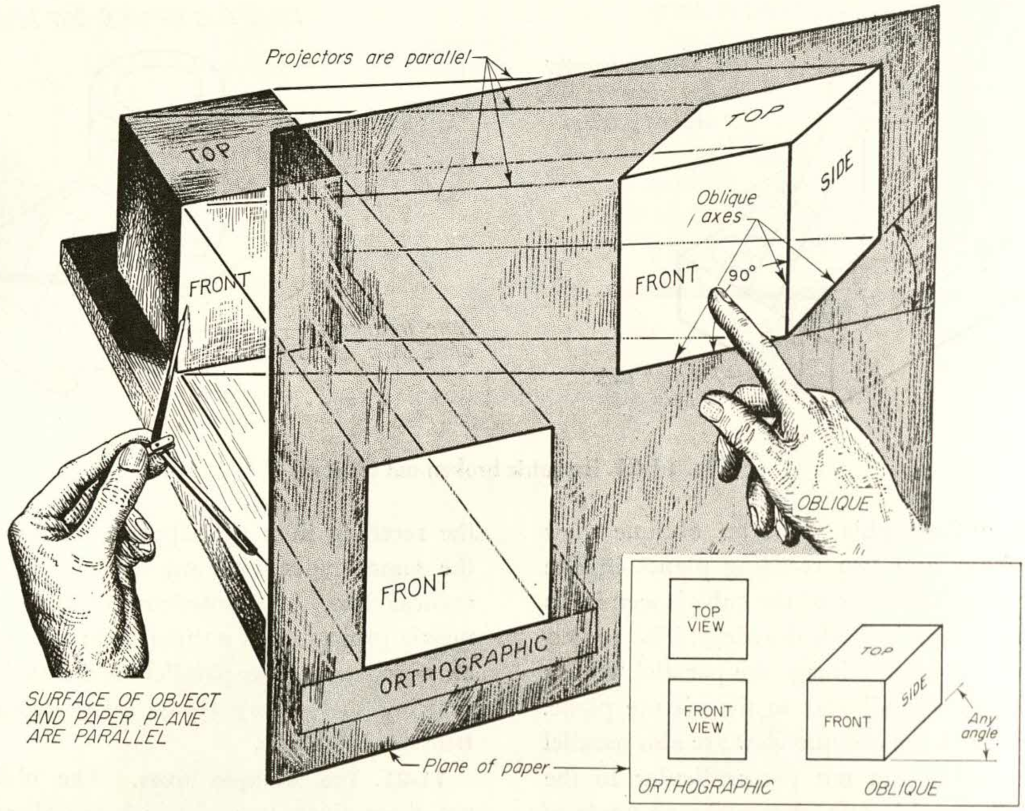


Fig. 11-23. Theory of oblique projection.

tions of the axes on the drawing sheet are not fixed except for the fact that the two axes resting on or parallel to the plane of the paper must make angles of 90° with each other.

11-22. Drawing a cube in oblique. Figure 11-25 illustrates the steps followed in making a simple oblique drawing. As in isometric drawing, the actual dimensions (or scaled dimensions) of a given object are measured along the main axes and any lines parallel to them. In the first step, the two mutually perpendicular axes lying on the drawing sheet are scaled to 2 in. In the next step, the receding axis is drawn at any angle with the horizontal and is also scaled to 2 in. In the third step,

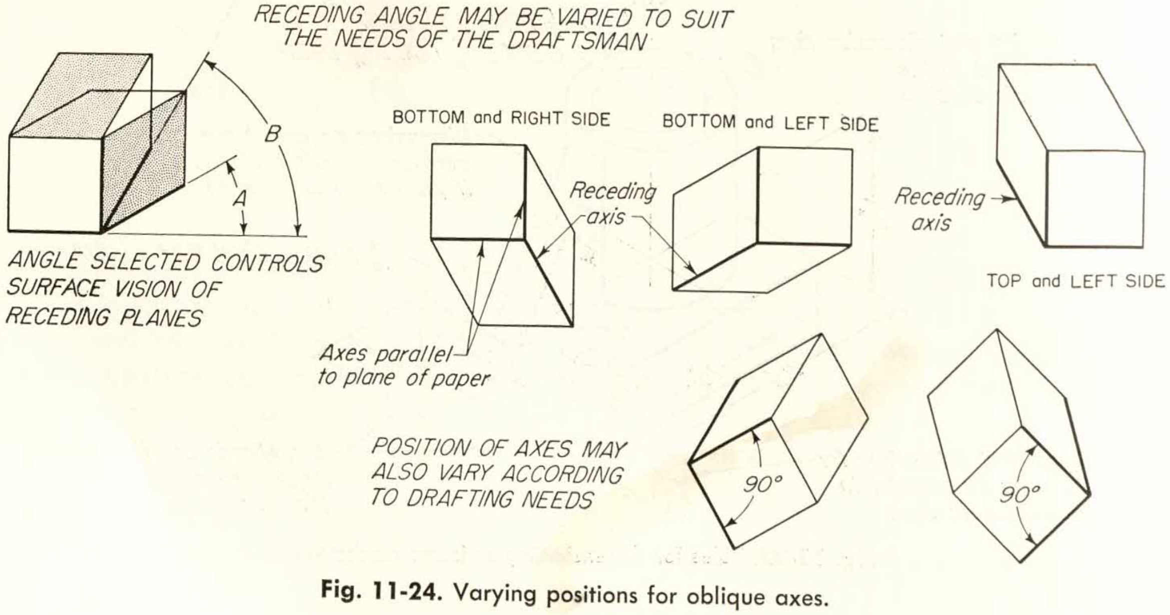

RECEDING ANGLE MAY BE VARIED TO SUIT THE NEEDS OF THE DRAFTSMAN
B
A
ANGLE SELECTED CONTROLS SURFACE VISION OF RECEDING PLANES
BOTTOM and RIGHT SIDE
Receding axis
BOTTOM and LEFT SIDE
Receding axis
TOP and LEFT SIDE
Axes parallel to plane of paper
POSITION OF AXES MAY ALSO VARY ACCORDING TO DRAFTING NEEDS
90°
90°

Fig. 11-24. Varying positions for oblique axes.

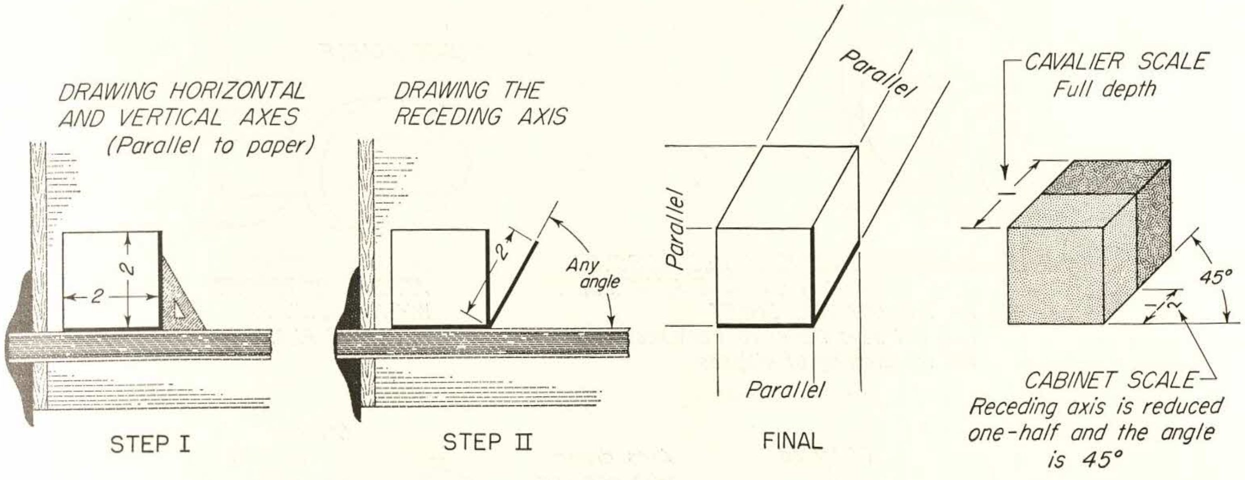


Fig. 11-25. Oblique drawing of a cube.

the remaining edges of the object are drawn parallel to the oblique axes to complete the drawing. Hidden lines indicating hidden edges are omitted. The receding angle is usually made 30, 45, or 60°.

To avoid the distortion that is often apparent in the final drawing, the receding axis may be foreshortened to satisfy the expectations of the human eye. If the angle is 45° and the receding axis is full scale, the drawing is in *cavalier style*. If the angle is 45° and the depth scale is reduced one-half, the result is known as a *cabinet drawing* (see Fig. 11-26). As a general rule, a more pleasing effect is obtained by reducing the scale of the receding axis.

11-23. Positions for rectangular forms. In making an oblique drawing, the usual procedure is to draw an object with the surface showing its most characteristic appearance parallel to the surface of the paper. In order to avoid undue distortion in the case of some forms, however, it is good practice to place them so that their long dimension lies parallel to the drawing surface (Fig. 11-27).

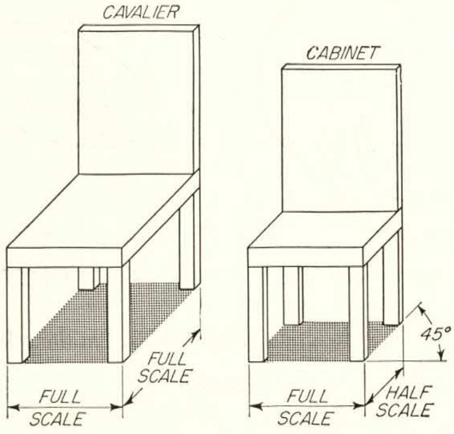


Fig. 11-26. Comparison of cavalier and cabinet drawing.

When drawing angles that appear on the receding or on the nonoblique planes, apply the methods of construction used in isometric (see Sec. 11-9).

11-24. Positions for circular and irregular curved forms. If objects whose contours are formed by circular arcs or irregular curves are to

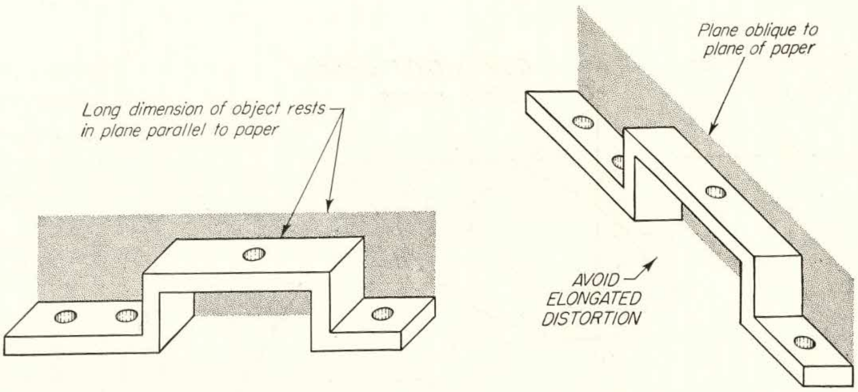

Long dimension of object rests in plane parallel to paper
Plane oblique to plane of paper
AVOID ELONGATED DISTORTION

Fig. 11-27. Avoiding distortion in oblique drawings.

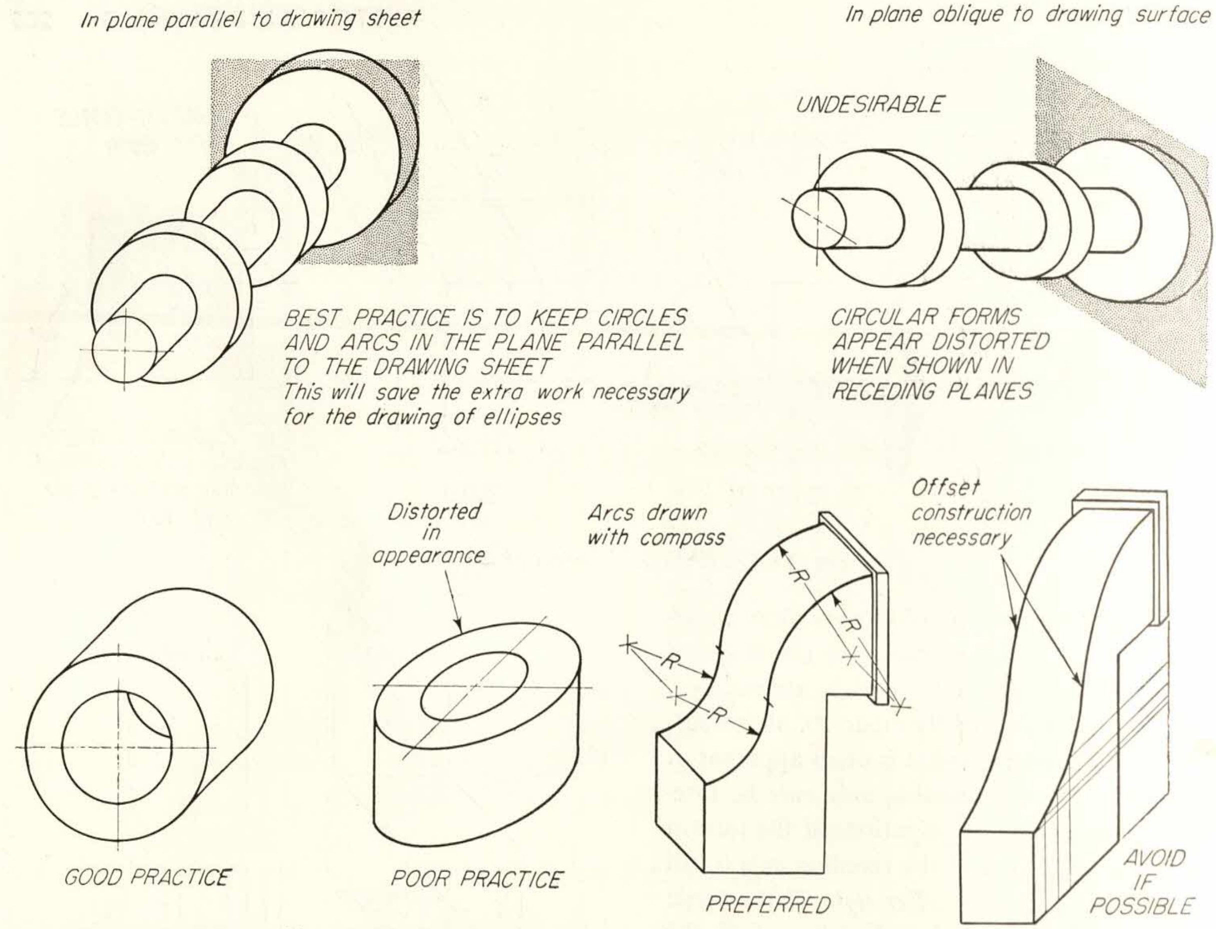

In plane parallel to drawing sheet
In plane oblique to drawing surface
UNDESIRABLE
BEST PRACTICE IS TO KEEP CIRCLES AND ARCS IN THE PLANE PARALLEL TO THE DRAWING SHEET
This will save the extra work necessary for the drawing of ellipses
CIRCULAR FORMS APPEAR DISTORTED WHEN SHOWN IN RECEDING PLANES
Distorted in appearance
Arcs drawn with compass
Offset construction necessary
R
R
R
R
GOOD PRACTICE
POOR PRACTICE
PREFERRED
AVOID IF POSSIBLE

Fig. 11-28. Positions for circular and irregular-curved forms.

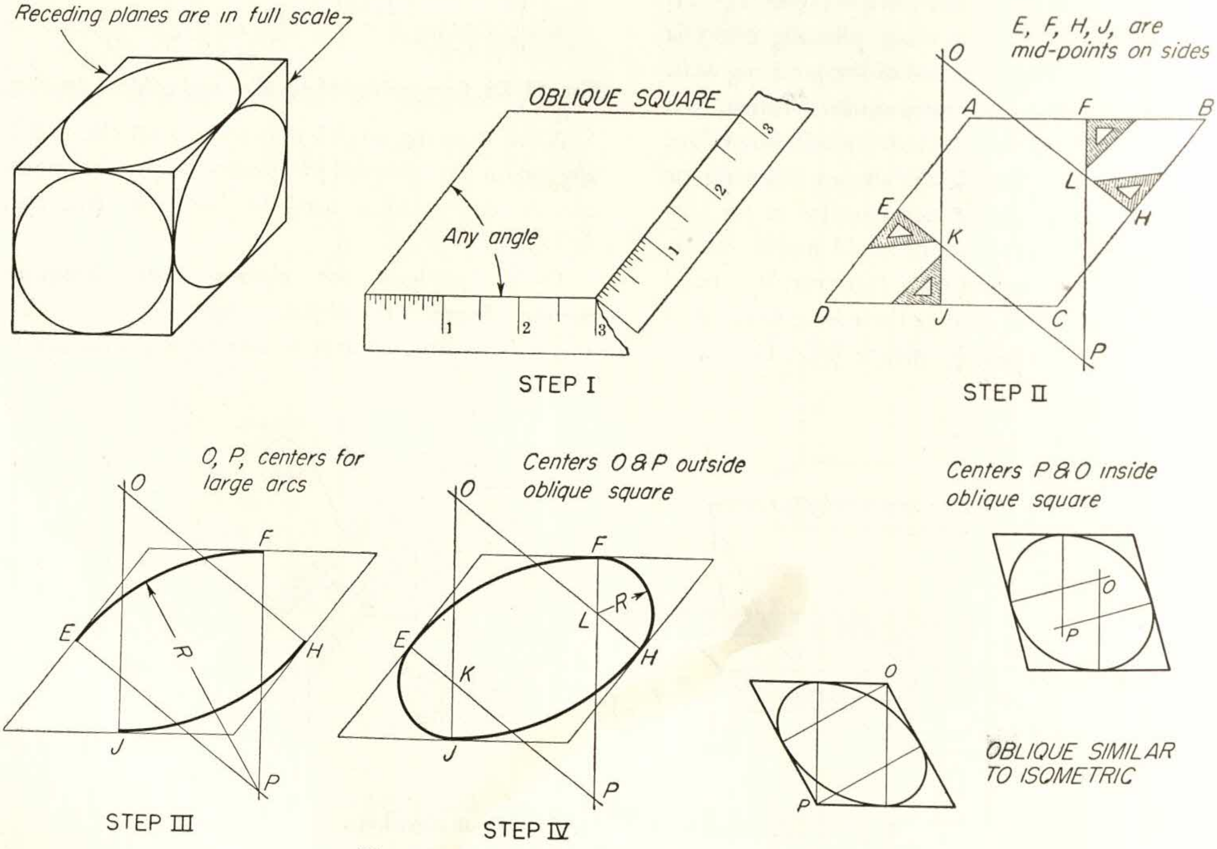

Receding planes are in full scale
OBLIQUE SQUARE
Any angle
1
2
3
1
2
3
STEP I
E, F, H, J, are mid-points on sides
O
A
F
B
L
E
H
K
D
J
C
P
STEP II
O, P, centers for large arcs
O
F
E
R
H
J
P
STEP III
Centers O & P outside oblique square
O
F
L
R
E
K
H
J
P
STEP IV
Centers P & O inside oblique square
O
P
O
P
OBLIQUE SIMILAR TO ISOMETRIC

Fig. 11-29. Drawing the circle as an ellipse.

be drawn, the outlines of these surfaces should be placed parallel to the plane of the paper. This saves both time and labor, because the circular curves can be drawn with a compass and the irregular curves can be produced in their true size and shape as they would appear in an orthographic view (see Fig. 11-28). Therefore, in the case of curved forms, it is usually best to place the circular or irregularly curved surface of an object, rather than its long dimension, parallel to the plane of the paper. In any case, try to select axes that will present the most pleasing and realistic drawing.

11-25. Construction of the circle as an ellipse. At times, it is necessary to show the circles on the receding planes, where they will appear as ellipses (see Fig. 11-29). If the receding axis is full scale, the ellipse may be drawn in the suitable oblique square by the four-center method. The method of construction is similar to that used for the isometric ellipse (see Sec. 11-10). However, note that only when the angles of the oblique square are similar to those of the isometric square will the construction of the resulting ellipse be like the isometric. In other cases, the centers for the large arcs may fall either inside or outside the parallelogram of the oblique square. The four-center method of constructing the oblique ellipse can be used only when the receding axis is full scale. When reduced scale is used, the ellipse must be located by rectangular coordinates.

Partial ellipses are drawn by locating the centers for the required portions of the arcs (see Fig. 11-30*a*). Circle arcs and irregular curves on a receding plane can also be drawn by transferring the intersecting points of rectangular coordinates with points on the curve appearing on the full-size orthographic (see Fig. 11-30*b*). Note in the illustration that the vertical axis resting in the plane of the drawing sheet is in full scale regardless of whether the receding axis is in full or half scale. Circular forms that must appear as ellipses on receding oblique planes always make a better appearance if the receding dimension is shortened.

11-26. Constructing the circle as an ellipse on any inclined plane. A method of projecting a circle to an inclined surface is shown in Fig. 11-31. An ellipse with a long diameter *XY* is to appear on the inclined surface *ABCD* shown in the top left corner of the illustration. The true shape of the circle is drawn on a plane lying parallel to the surface of the paper as shown. The vertical center line *YZ* for the circle and the inclined center line *XY* for the ellipse intersect at *Y*. The points that form the path of the ellipse are found by using a system of rectangular coordinates in the manner explained in Sec. 11-9. The points on the circle are projected to the coordinates on the inclined plane of the ellipse in a direction parallel to the receding axis. Not only is this construction useful for the drawing of ellipses in oblique projections: it may also be used to construct an ellipse on any inclined surface, including constructions in ordinary orthographic drawing.

11-27. Rounded edges. The conventional manner of treating the rounded intersections on parts, especially on castings, is illustrated in Fig.

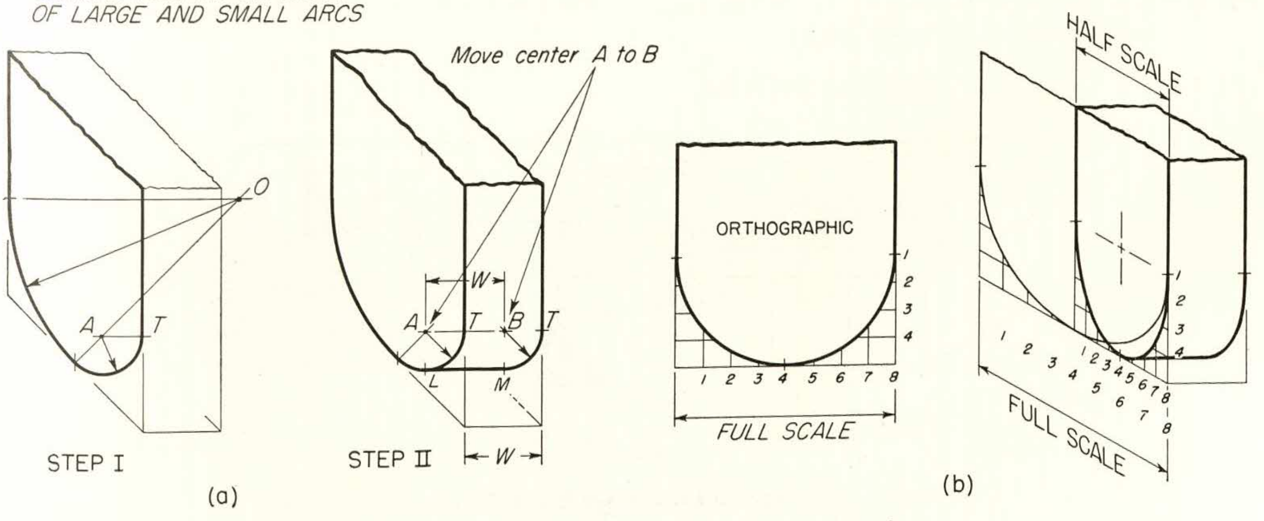


Fig. 11-30. Drawing partial ellipses for curved ends.

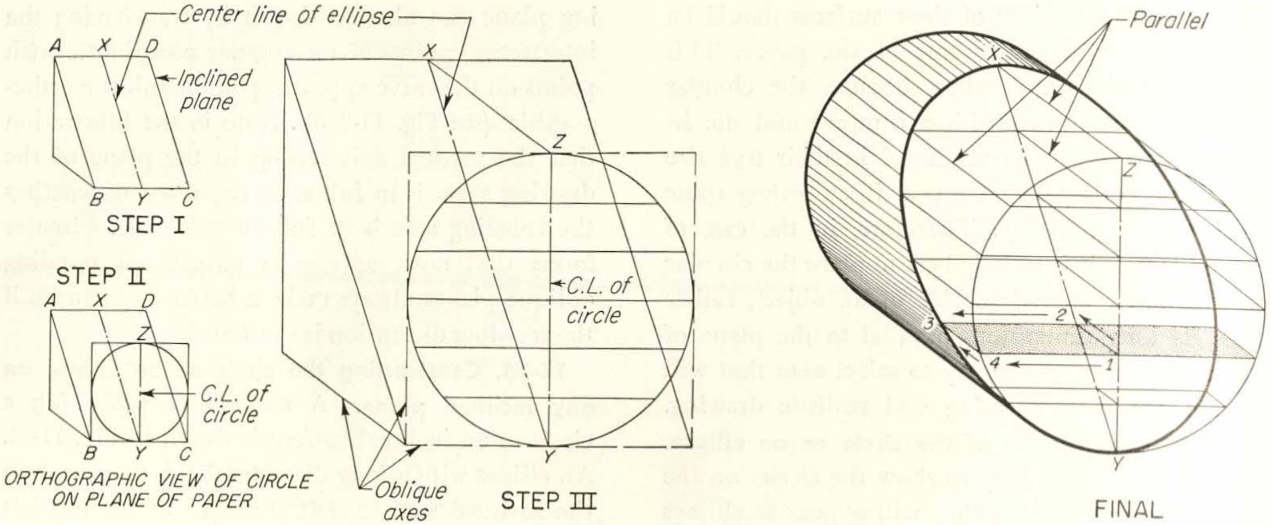


Fig. 11-31. Drawing the ellipse on an inclined surface.

11-32. Note also the manner of showing screw threads. The full radius of the nearest circle of the cylinder has been struck off at regular intervals along the receding oblique axis of the hole, allowing only the portions of the arcs within the circle to remain on the finished drawing.

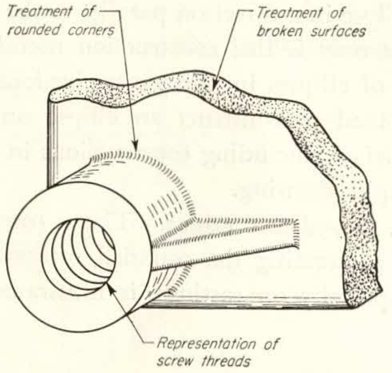

Treatment of rounded corners
Treatment of broken surfaces
Representation of screw threads

Fig. 11-32. Conventional treatment of rounded corners, screw threads, and broken edges.

11-28. Oblique-section views. In general, the procedures employed in drawing isometric sections are used in the preparation of oblique-section views. Oblique full sections (Fig. 11-33) are rarely used, because the cutting plane, passing completely through the object along its center line, often makes it impossible to show important external features. The half section (Fig. 11-34) and the broken-out section are more frequently employed, because these enable the draftsman to show external as well as internal details.

11-29. Oblique drawing and dimensioning. In preparing an oblique drawing, it is important to keep in mind that all lines, angles, circles, circle arcs, and irregular curves project in their true size and shape when drawn parallel to the drawing surface, no matter how far into the background they may appear to recede. This fact was deemed most important in selecting the position of the ob-

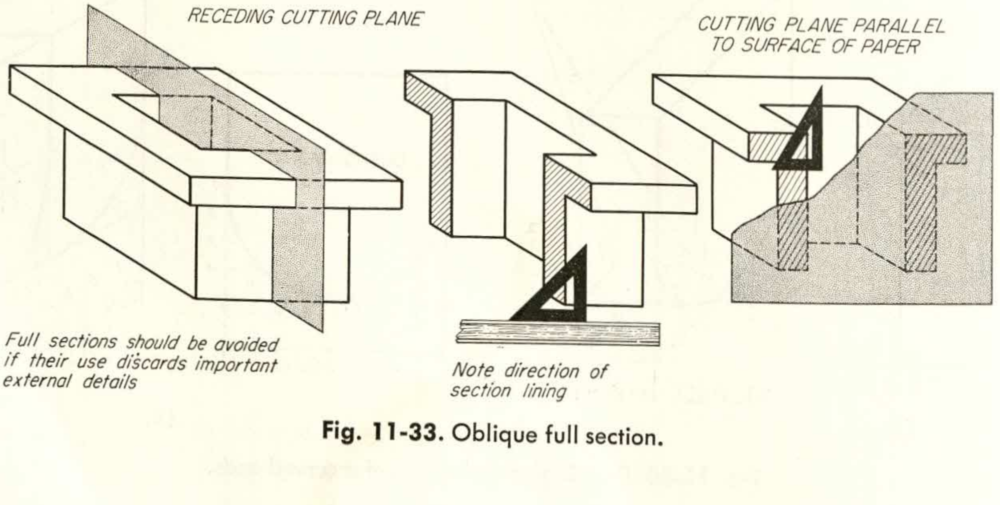

RECEDING CUTTING PLANE
CUTTING PLANE PARALLEL TO SURFACE OF PAPER
Full sections should be avoided if their use discards important external details
Note direction of section lining

Fig. 11-33. Oblique full section.

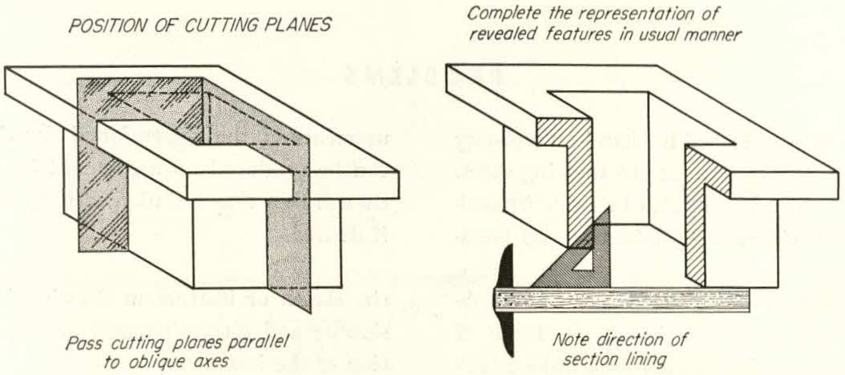

POSITION OF CUTTING PLANES
Complete the representation of revealed features in usual manner
Pass cutting planes parallel to oblique axes
Note direction of section lining

Fig. 11-34. Oblique half section.

ject shown in Fig. 11-35, and the long axis of the object accordingly was placed on a receding plane rather than parallel to the surface of the drawing paper. In Step I, the center lines and the boxlike framework are first drawn, after which the proper locations of the centers for the required arcs and circles are marked off. Step II shows the semicircles of the large arcs terminating at the tangent points of the arcs and the straight-line edges. The circles for the holes are then drawn in, and the portions of the circles located on the farther planes are shown. When important details are obscured, parts of the object may be sectioned away to reveal them. Center lines are added to facilitate the dimensioning procedure illustrated in the final drawing. Note that, as in isometric drawing, the dimension figures, dimension lines, etc., are drawn to lie in the plane of the surface they dimension.

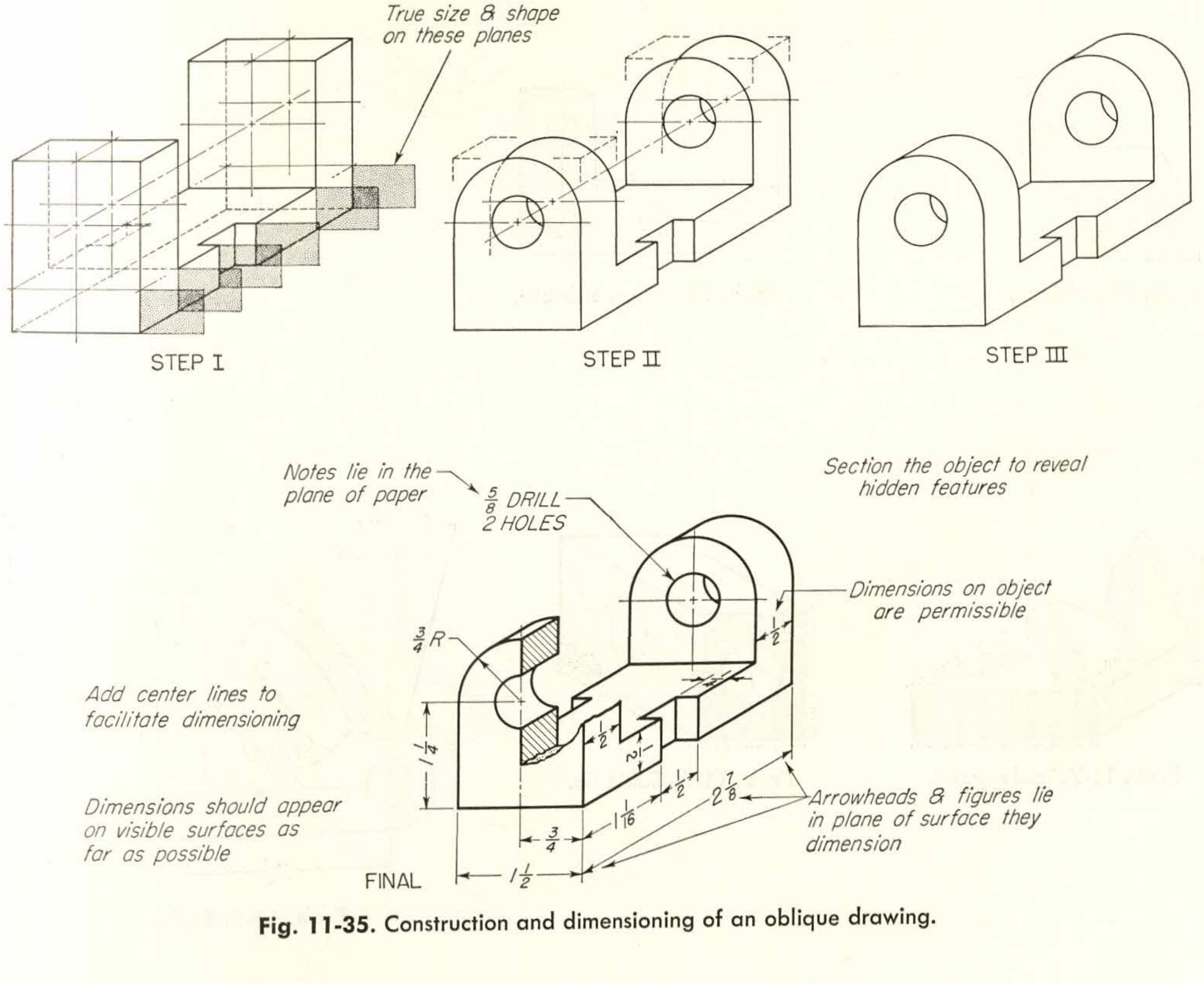
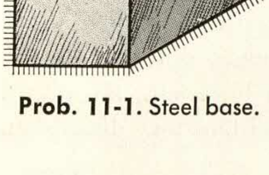

True size & shape on these planes
STEP I
STEP II
STEP III
Notes lie in the plane of paper
5/8 DRILL 2 HOLES
Section the object to reveal hidden features
Dimensions on object are permissible
3/4 R
1/2
Add center lines to facilitate dimensioning
1 1/4
1/2
1/2
1/2
2 7/8
1 1/16
Arrowheads & figures lie in plane of surface they dimension
Dimensions should appear on visible surfaces as far as possible
3/4
1 1/2
FINAL

Fig. 11-35. Construction and dimensioning of an oblique drawing.

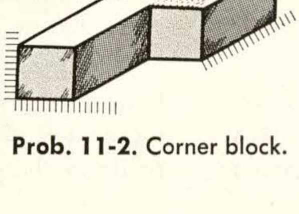
PROBLEMS

These problems may be sketched freehand on ordinary sketch paper at a suitable scale to fit the drawing sheet. Instrument drawings to scale may also be made by scaling the objects with dividers or by following the measurements of the dimensioned drawings. Each problem can be produced on a standard 8½- by 11-in. sheet, although they may be enlarged to fit an 11- by 17-in. sheet if desired.

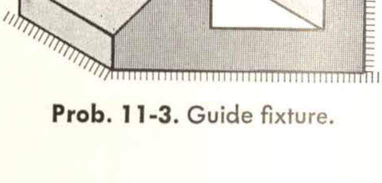
Problems 11-1 to 11-10. The given figures are oblique drawings. Make a freehand thumbnail sketch of each problem as it appears in oblique; then make a full-size sketch or instrument drawing in isometric. Dimensioning and sectioning may be required at the suggestion of the instructor.



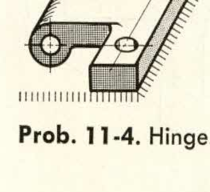
Prob. 11-1. Steel base.



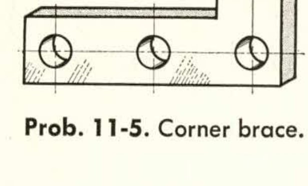
Prob. 11-2. Corner block.



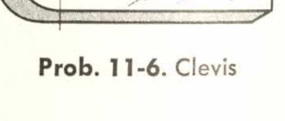
Prob. 11-3. Guide fixture.



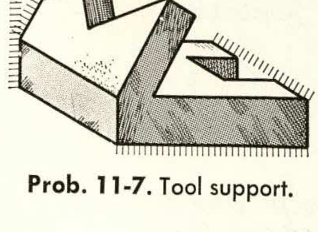
Prob. 11-4. Hinge.



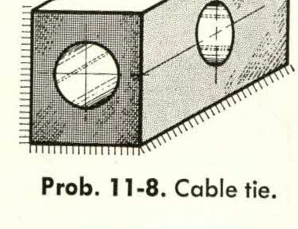
Prob. 11-5. Corner brace.



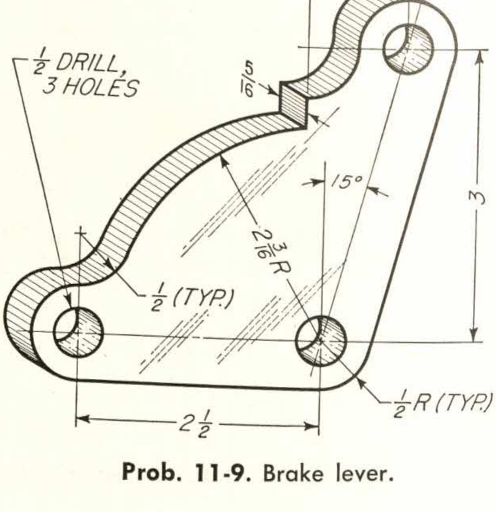
Prob. 11-6. Clevis



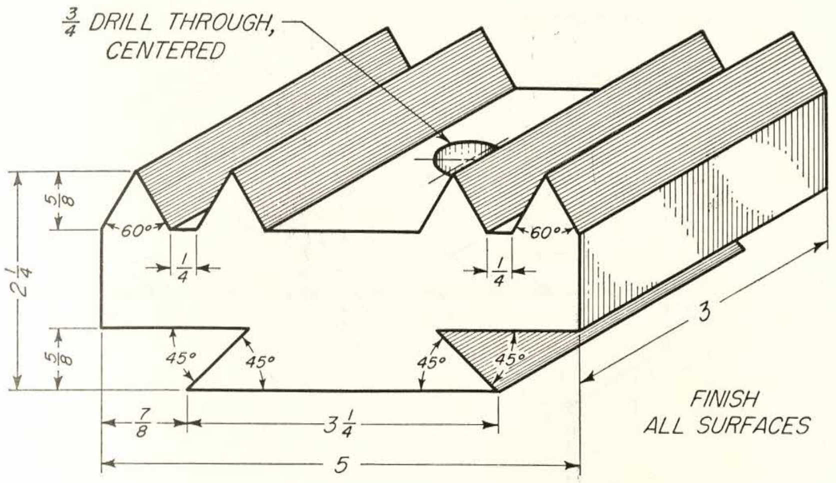
Prob. 11-7. Tool support.



Prob. 11-8. Cable tie.

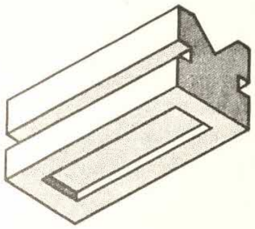


Prob. 11-9. Brake lever.

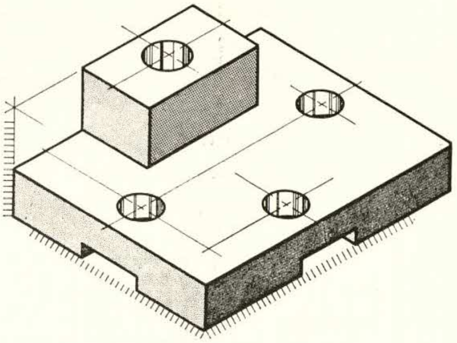


Prob. 11-10. Sliding clip.

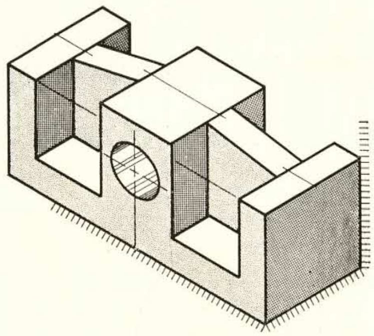
Problems 11-11 to 11-18. The illustrations are isometric drawings. Make a thumbnail sketch of each problem as an isometric; then prepare a large-scale freehand sketch or an instrument drawing of the object in oblique. Dimensioning and sectioning may be required at the suggestion of the instructor.



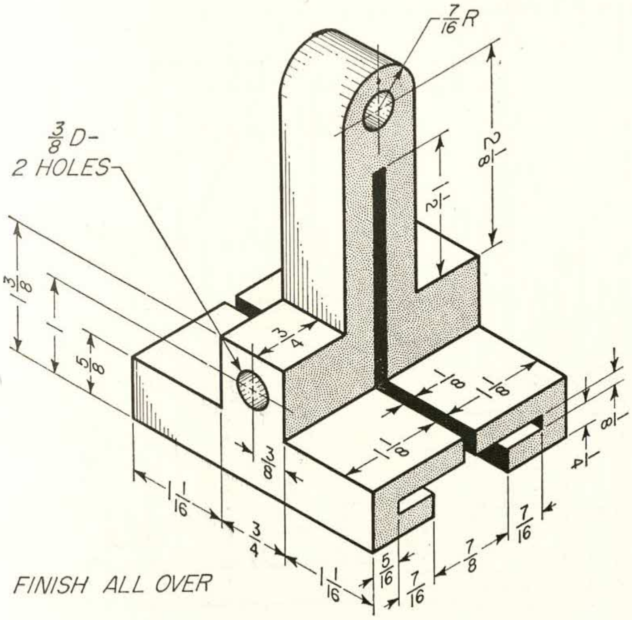
Prob. 11-11. Clamp base.



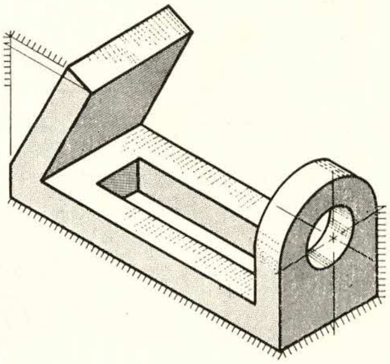
Prob. 11-12. Drill guide.



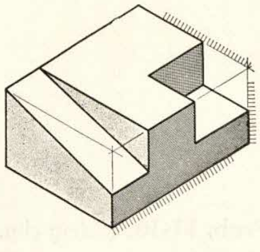
Prob. 11-13. Rod guide.



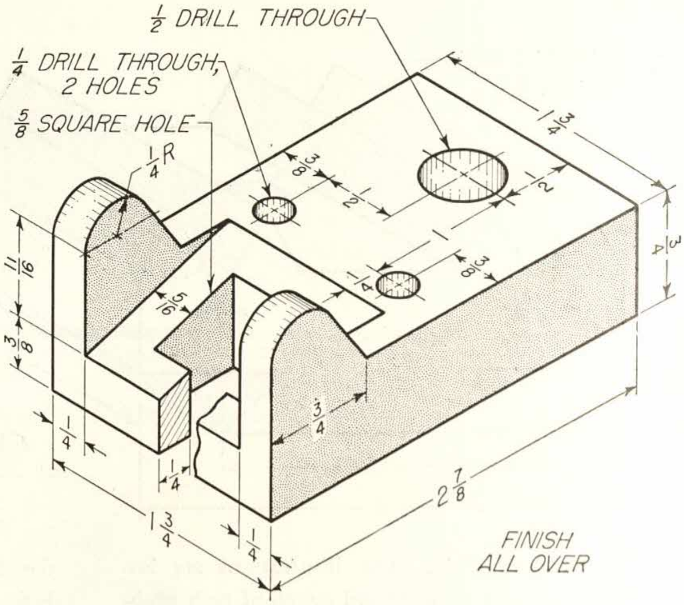
Prob. 11-14. Adjusting clamp.



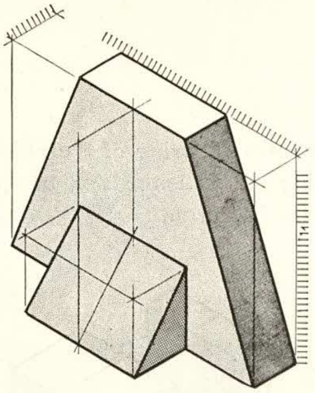
Prob. 11-15. Cable adjustor.



Prob. 11-16. Stop block.

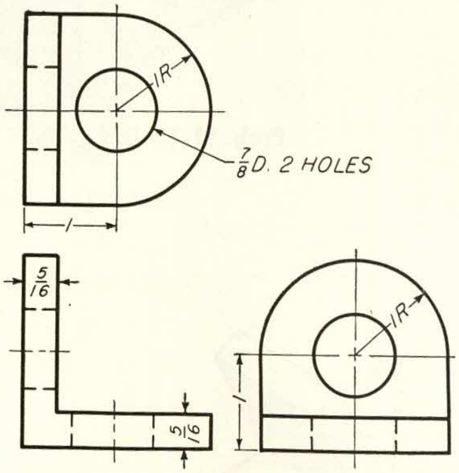


Prob. 11-18. Sliding block.

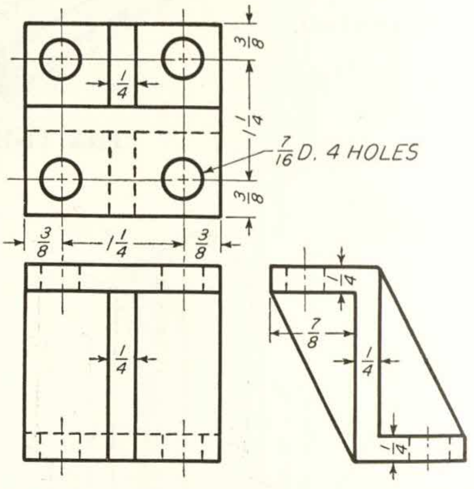


Prob. 11-17. Base anchor.

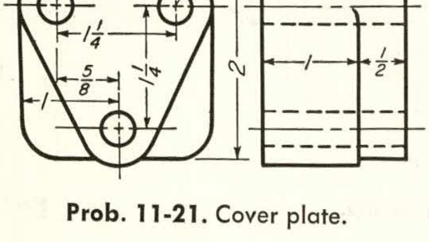
Problems 11-19 to 11-38. The orthographic views of various objects are given. They may be assigned as either isometric or oblique problems in which the student may be required to make a pictorial thumbnail sketch before working with instruments. Sectioning practices should be used where desirable, and some of the drawings should be dimensioned in order to give the student practice in this phase of the work.



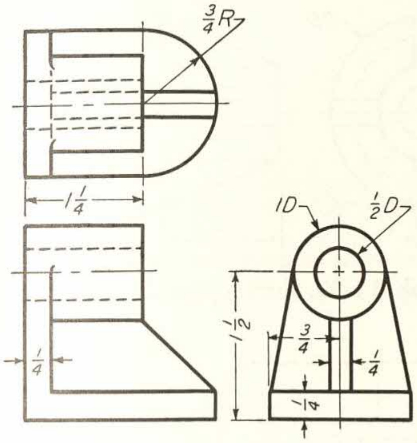
Prob. 11-19. Rod anchor.



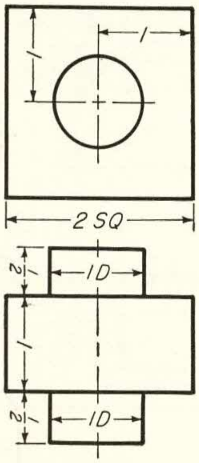
Prob. 11-20. Beam support.



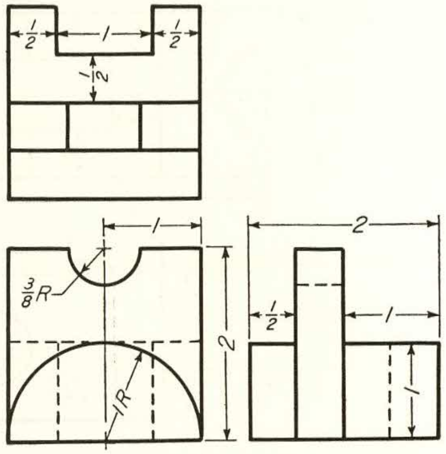
Prob. 11-21. Cover plate.



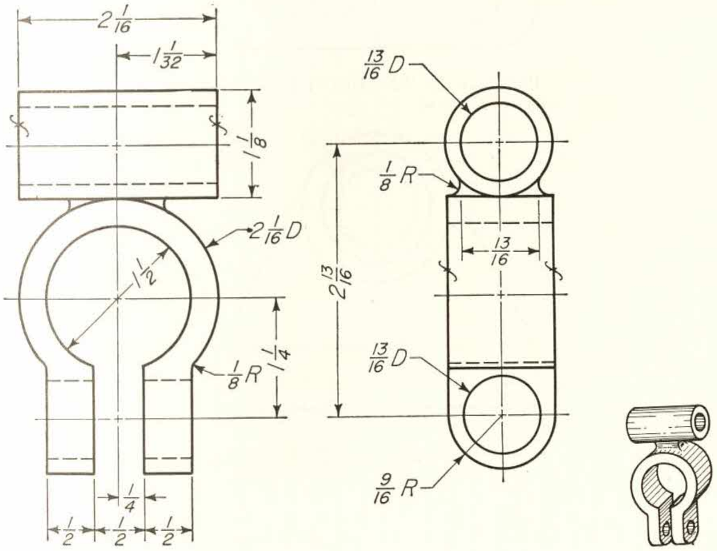
Prob. 11-22. Shaft support.



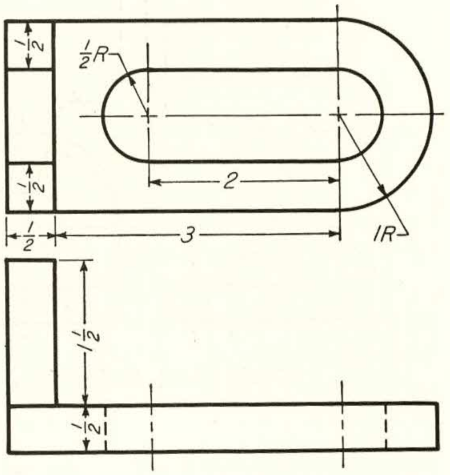
Prob. 11-23. Plug.



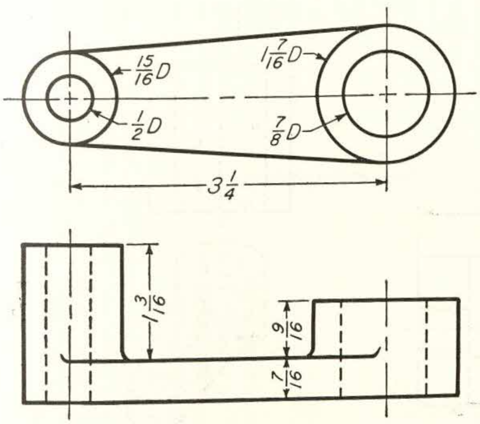
Prob. 11-24. Rail support.



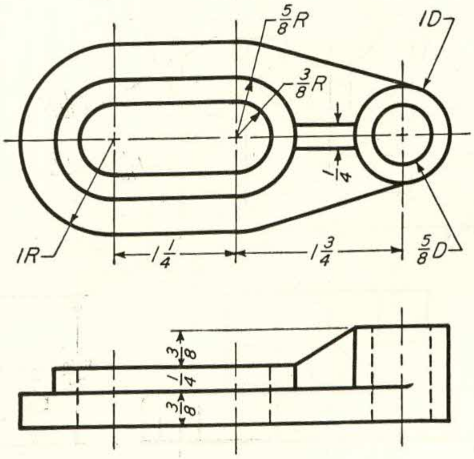
Prob. 11-25. Cable clamp.



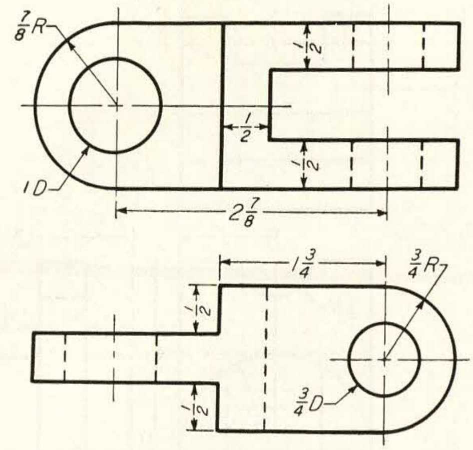
Prob. 11-26. Sliding adjustor.



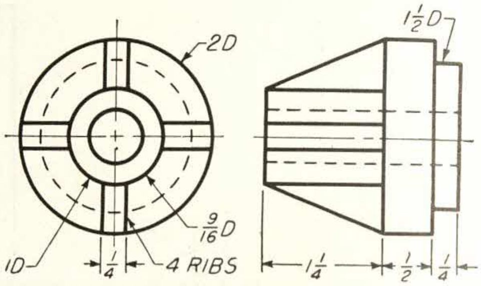
Prob. 11-27. Link.



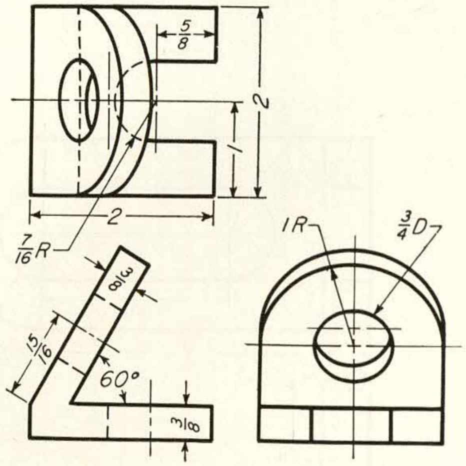
Prob. 11-28. Adjusting lever.



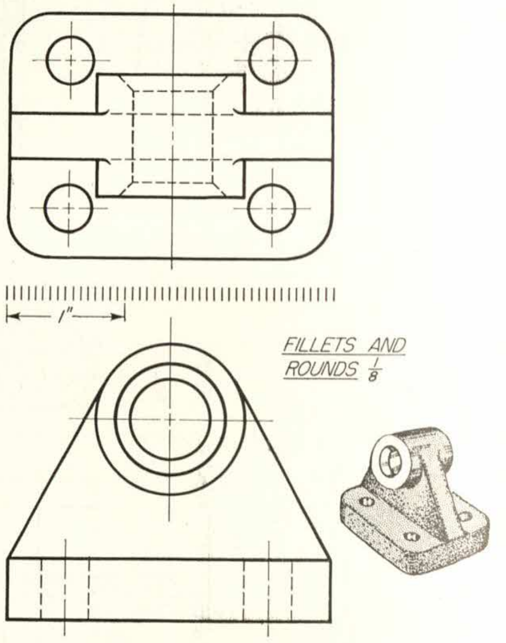
Prob. 11-29. Link.



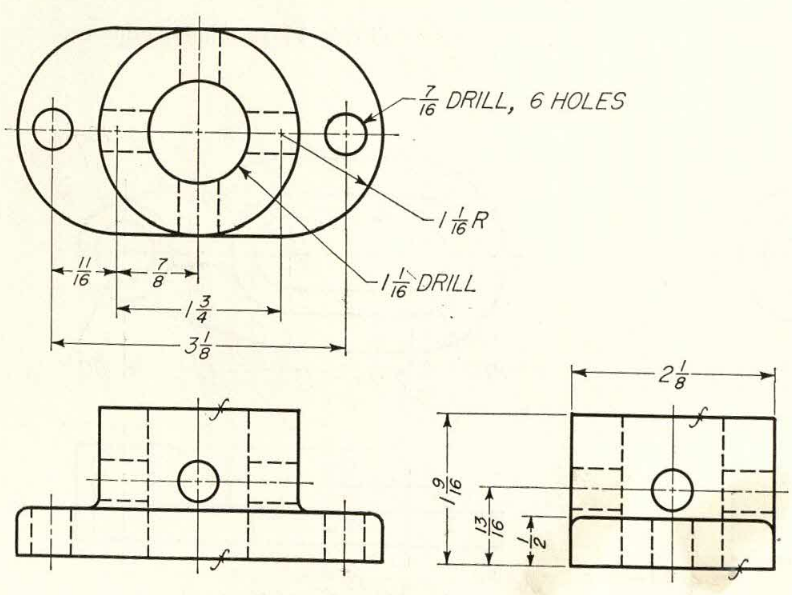
Prob. 11-30. Shaft support.



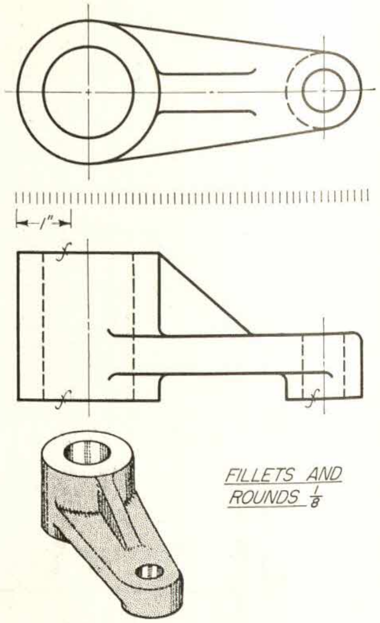
Prob. 11-31. Rod anchor.



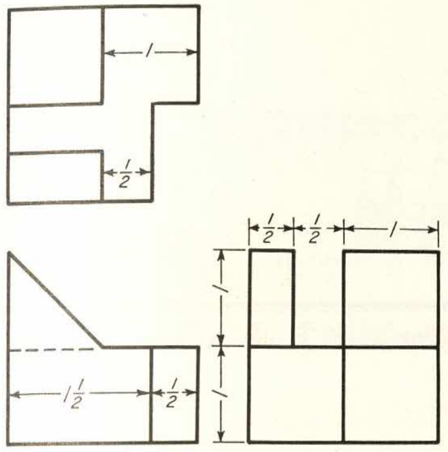
Prob. 11-32. Shaft support.



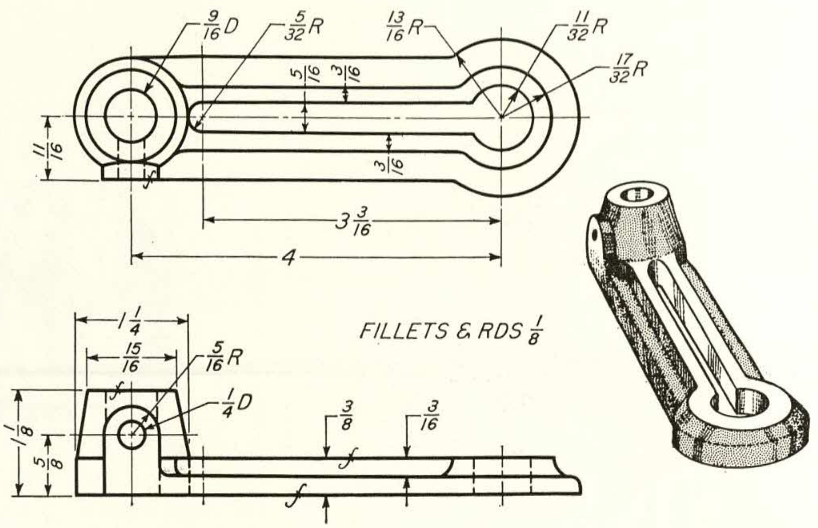
Prob. 11-33. Rod support.



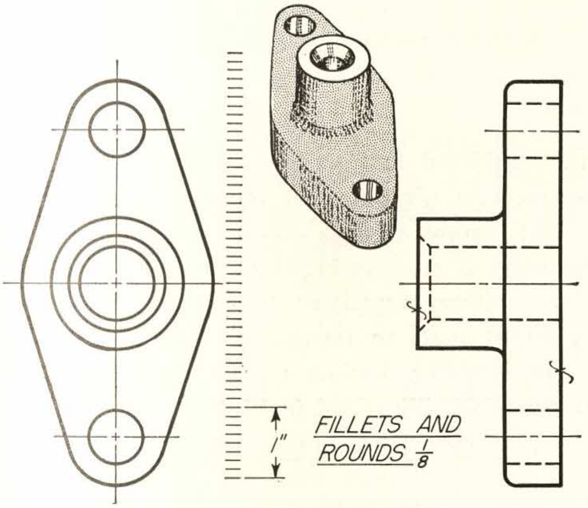
Prob. 11-34. Rod guide.



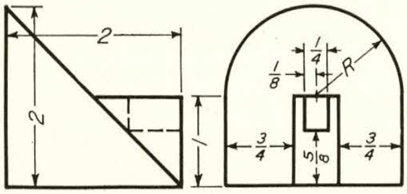
Prob. 11-35. Fixture base.



Prob. 11-36. Tool support.



Prob. 11-37.

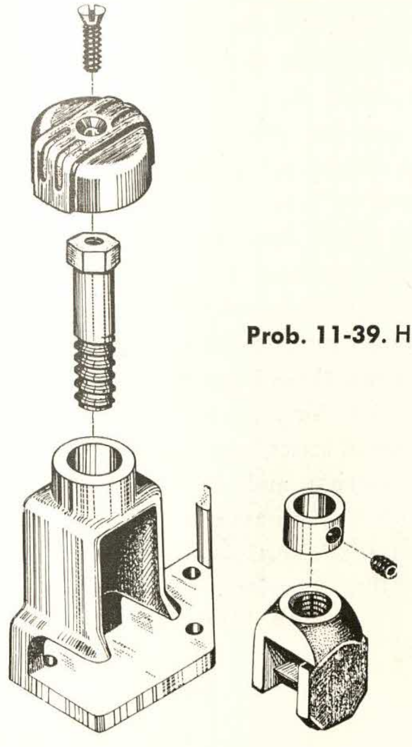


Prob. 11-38. Fixture.

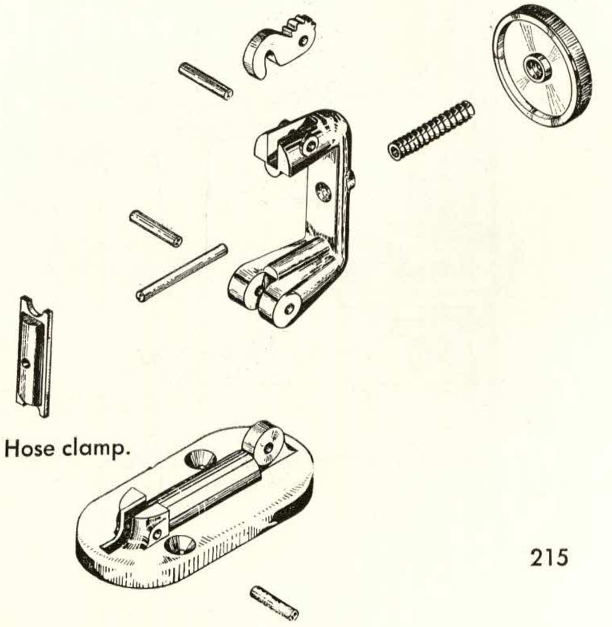
Problems 11-39 and 11-40. These problems are offered to encourage the making of preparatory outline pictorial thumbnail sketches with the addition of lines that give tonal quality and the feeling of solidity and roundness to the parts.

Make pictorial thumbnail sketches of the various parts of the two clamps shown here in isometric drawing. Make your sketches about twice the size they appear in the illustrations.

The instructor may assign additional problems for pictorial drawing by selecting suitable objects from other problem sections elsewhere in the text.



Prob. 11-39. Hose clamp.



Prob. 11-40. Hose clamp.

Chapter 12

COMMON FASTENERS

As an engineer or draftsman, you should become familiar with the design and representation of fasteners, for although there are hundreds of thousands of varieties of special kinds available, the fundamental, or basic, features found in all can be explained in a discussion of the common types. Fasteners appear frequently in the drawing of machine assemblies. A number of the more common fasteners are shown in Fig. 12-1. Rivets and welds are considered to be permanent fasteners. Bolts, screws, keys, pins, etc., are removable fasteners.

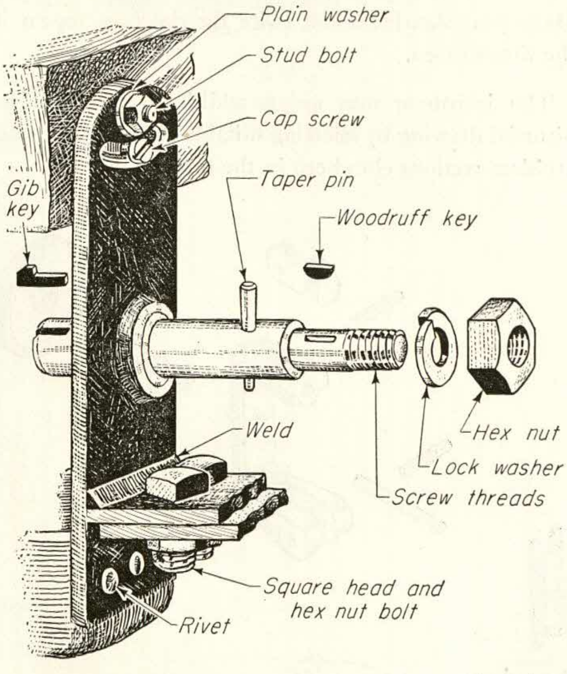
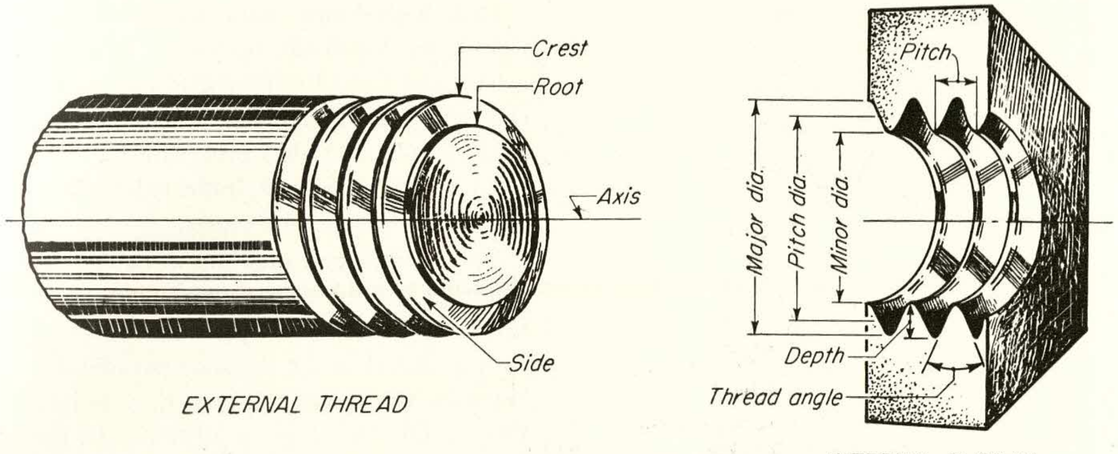


Fig. 12-1. Common fastening devices.

12-1. Screw threads. Basic screw-thread terminology is given in Fig. 12-2. Screw threads have three primary functions: to hold parts together, to adjust parts in relation to each other, or to transmit power. Various types of threads in common use are illustrated in Fig. 12-3. The sharp V (which is fast falling into disuse) and the unified or American (National) Standard are used for holding parts together. The square, the Acme, and the Browne & Sharpe worm threads are used to transmit power. The buttress thread transmits power in one direction only. The Whitworth and British Association Standard are British threads, the former being the British Standard. The knuckle thread is a rolled thread used for light sockets, etc., while the standard pipe thread may be either tapered or straight and is used to join pipe sections. In general, any standard thread may be shown as a schematic or simplified representation on the drawing sheet if its proper specifications and complete dimensions are given by note (see Secs. 12-5 to 12-9).

12-2. Unified screw-thread series. The International Organization for Standardization has selected six basic thread series, together with several special types of foreign and American threads, as unified standards to facilitate international manufacturing procedures. The threads that make up the unified screw-thread series are similar to the



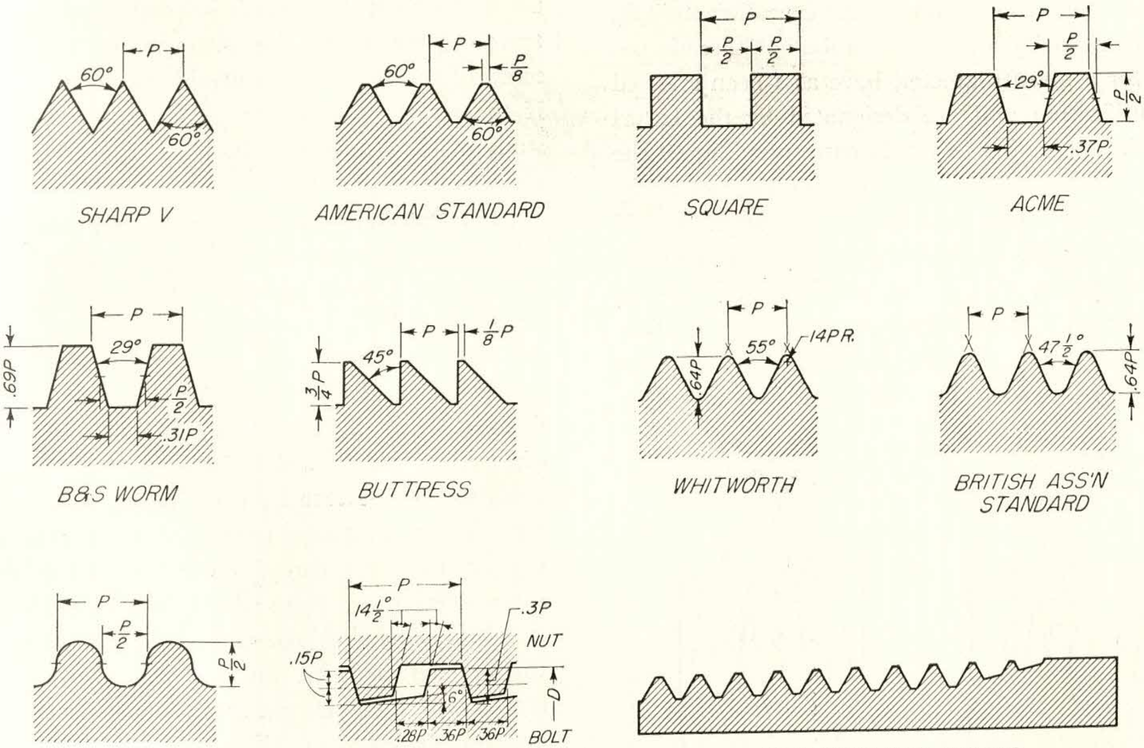
EXTERNAL THREAD

INTERNAL THREAD

Fig. 12-2. Screw-thread terminology.

American Standard threads but have rounded roots and flat or rounded crests on the external threads and flat crests and roots on the internal threads (see Fig. 12-4). A unified thread may be represented in detail, schematically, or simplified by using the same representations employed to show the American Standard types (see Fig. 12-16).

The various threads of the unified series differ from each other in the number of threads per inch for a given diameter. The unified threads are described completely in ASA B1.1—1949. The unified coarse-thread series is recommended for general industrial use and is designated by the abbreviation UNC. The fine-thread series employed in the



SHARP V

AMERICAN STANDARD

SQUARE

ACME

B&S WORM

BUTTRESS

WHITWORTH

BRITISH ASS'N STANDARD

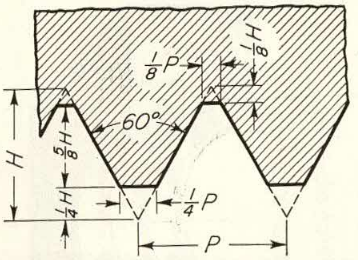
KNUCKLE

DARDELET

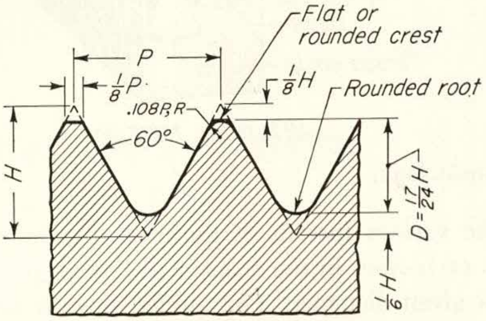
STANDARD PIPE THREAD
For dimensions see fig. 12-18

ALL STANDARD THREADS MAY BE SHOWN SCHEMATICALLY OR SIMPLIFIED ON ENGINEERING DRAWINGS

Fig. 12-3. Screw threads (sections).



UNIFIED INTERNAL THREAD



UNIFIED EXTERNAL THREAD

Fig. 12-4. Unified thread.

aircraft and automotive fields is indicated by the abbreviation UNF. A few of the extra-fine threads, characterized by a greater number of threads per inch for a given diameter, have also been selected for unification and are designated by the letters UNEF. The unified threads corresponding to the American Standard 8, 12, and 16 series are designated 8UN, 12UN, and 16UN. (Although the U may be dropped in designating any thread of the unified system, this is not recommended by the author until widespread usage overcomes the likelihood of errors.) Unified threads range between ¼ and 6 in. in diameter (see Appendix, Table 5).

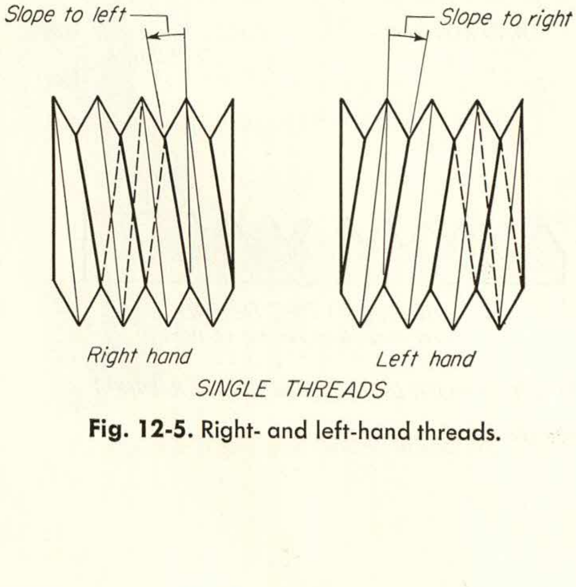


Fig. 12-5. Right- and left-hand threads.

12-3. Right-hand and left-hand threads. A right-hand thread advances when turned clockwise; a left-hand thread advances when turned counterclockwise (see Fig. 12-5). All threads are considered right-hand unless otherwise specified. A left-hand thread is always indicated with the letters LH in the thread specification.

12-4. Single and multiple threads. If a thread consists of a single continuous ridge, it is a single thread and its lead is equal to its pitch. The *pitch P* of a thread is the distance parallel to the axis, between two similar succeeding points on the thread. The *lead L* is the distance the thread travels in one complete turn. On a single thread, the lead and the pitch are equal; on multiple threads, the lead is always greater than the pitch (see Fig. 12-6). Multiple threads are found on many types of locking devices and are often used where travel instead of power is desired. Two or more ridges cut side by side produce this type of thread. The lead of the double thread is twice its pitch, and a nut would travel twice as far as on a single thread in one complete turn of the screw. The lead of a triple thread is three times its pitch, and the screw travels three times the distance a single-thread screw of the same design would travel in one turn. If the screw is drawn in profile, as in Fig. 12-6, study of the thread will indicate whether it is single, double, triple, etc.

12-5. Detailed screw-thread representation. The true projection of a screw thread would take the form of a series of helices. However, the representation of helical curves is a time-consuming and tedious procedure, and in practice the helical curves are not drawn except for very large-diameter threads. Instead, the detailed representation is often employed in which the helices are shown as straight lines. Actually, even this procedure has been further simplified so that in commercial-drafting practice only threads over 1 in. in diameter, special designs, or cases where the less realistic appearance might be confusing are represented in this detailed manner. Threads of smaller diameter are shown either schematically or simplified as discussed in Secs. 12-7 to 12-9.

Figure 12-7 illustrates the semiconventional representation of the sharp V, the unified, and the American Standard thread. Start by laying out the axis, the outside diameter, and the length of

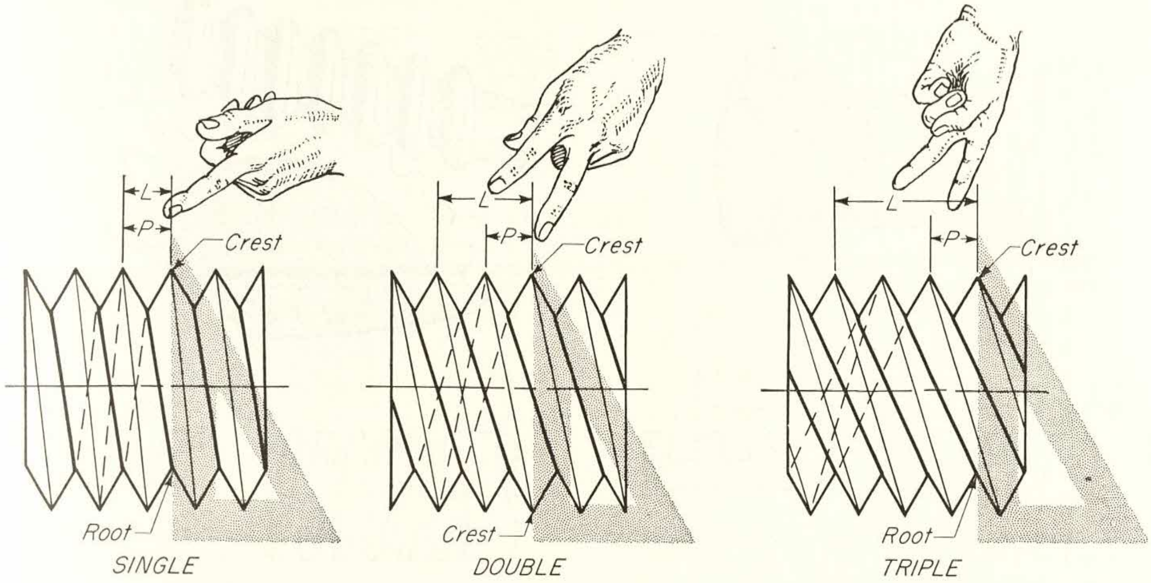


Fig. 12-6. Single and multiple threads.

the screw thread. Find the number of threads to the inch for the given diameter by referring to Table 5 in the Appendix. The pitch distance, which is found by dividing 1 in. by the number of threads per inch, is then set off along the full length of the thread on the upper line representing the major diameter. This procedure is repeated along the lower line of the diameter except that a distance equal to one-half the pitch is marked off first. Draw straight lines connecting the pitch points to indicate the crest lines. Next draw 60° lines through the pitch points to intersect as shown in the illustration. Join these intersections to produce the root lines. Note that root and crest lines are not parallel.

In drawing single threads and all odd-numbered multiple threads, a root is always opposite a crest; in drawing even-numbered multiple threads, a root is opposite a root and a crest is opposite a crest (see Fig. 12-6). For right-hand external threads, the

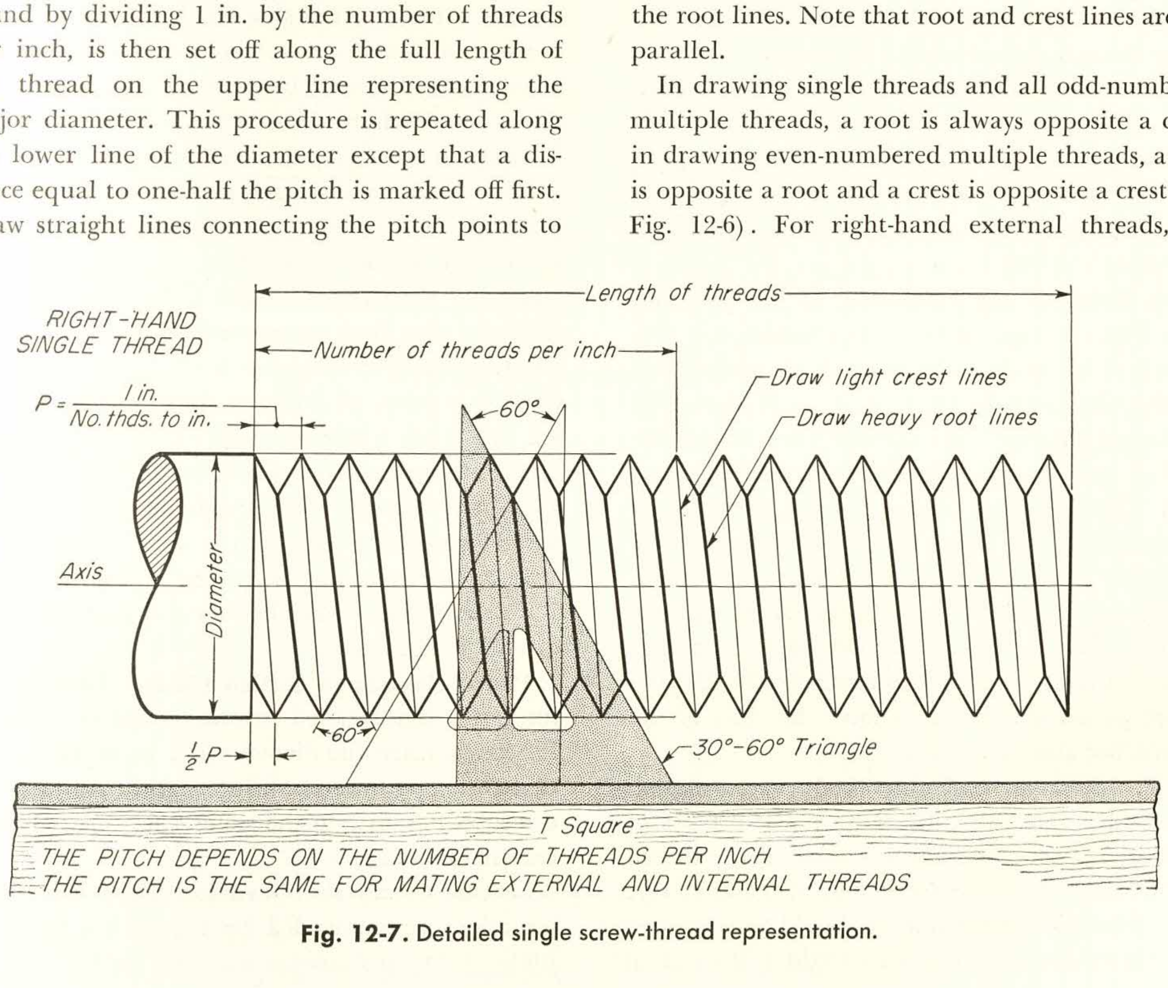
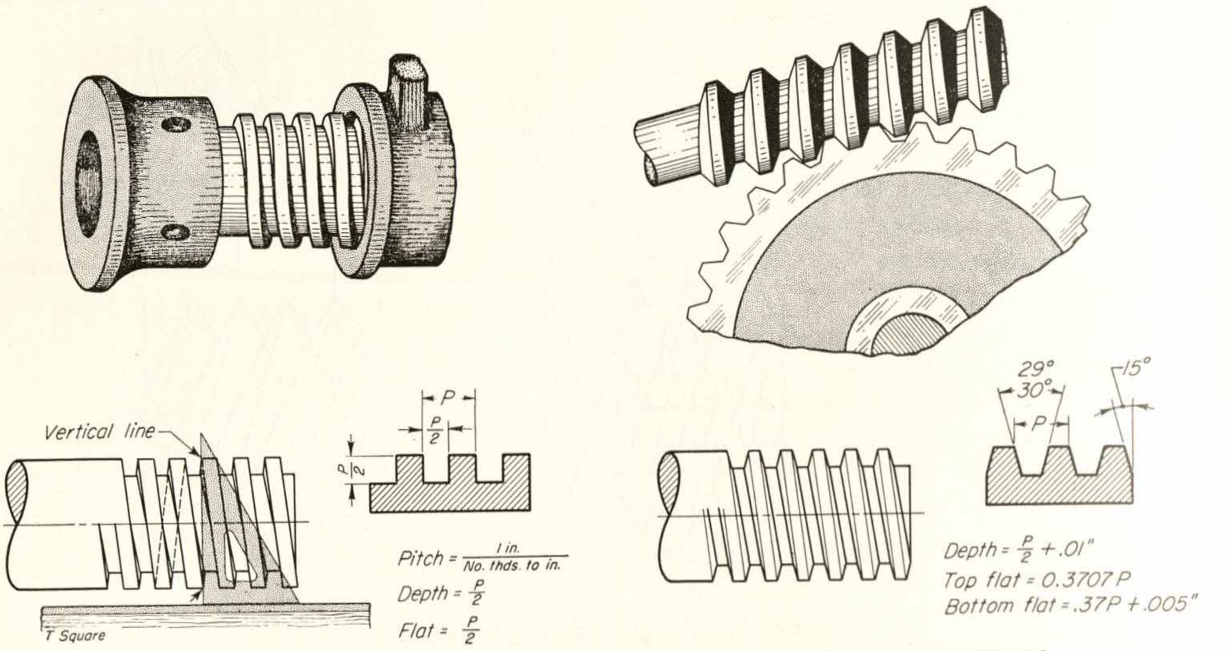

Length of threads
RIGHT-HAND SINGLE THREAD
Number of threads per inch
P = 1 in. / No. thds. to in.
60°
Draw light crest lines
Draw heavy root lines
Axis
Diameter
60°
½P
30°-60° Triangle
T Square
THE PITCH DEPENDS ON THE NUMBER OF THREADS PER INCH
THE PITCH IS THE SAME FOR MATING EXTERNAL AND INTERNAL THREADS

Fig. 12-7. Detailed single screw-thread representation.



SQUARE SINGLE THREADS

ACME SINGLE THREADS

Fig. 12-8. Detailed representation of square and Acme threads.

slope lines lean toward the left; for right-hand internal threads (when shown in section—see Sec. 12-10), the slope lines lean toward the right. Left-hand external and internal threads are drawn with the same general procedure, except that the slope is different, of course, and the distance equal to one-half the pitch is laid off along the top line rather than along the bottom.

12-6. Detailed representation of square and Acme threads (Fig. 12-8). Lay out the axis and the major diameter. The number of threads per inch for the given diameter (for internal as well as external threads) may be found in the Appendix. Lay out the pitch distances along the upper major diameter line. Then lay out these pitch distances along the lower line by starting one-half pitch away from a vertical drawn through the top starting pitch point. Locate the flat crests and valleys as shown in the sectioned views. The final steps require care in order to make certain that the proper points are joined to form the sides of the threads. See also Fig. 12-13.

12-7. Schematic and simplified representation of threads. The ASA has approved two types of conventional thread symbols: the *schematic* thread and the *simplified thread* (see Figs. 12-9 and 12-10). The schematic representation should not be used for hidden internal threads or sections of external threads. Although the simplified form saves drafting time, it is not so pleasing or so effective as the schematic and should be used mainly for internal threads and where there is no possibility of confusion with other graphic details.

12-8. Drawing schematic threads. The steps in drawing the schematic thread are shown in Fig. 12-11. The alternate long thin lines represent the crests and the shorter heavier lines the roots. The crest and root lines are spaced by eye, since no attempt is made to show the actual pitch. However, when a number of different sizes of screw threads are shown on a drawing, the spacing should vary sufficiently to give the worker an idea of the difference in the number of threads on one part compared with those on another.

12-9. Drawing the simplified threads. Figure 12-12 shows the steps to be followed in the drawing of simplified threads.

12-10. Threads in section views. Figure 12-13 illustrates the detailed representation of a thread in section when the diameter is 1 in. or over. Note that the slope lines of an internal thread lean in a direction opposite to the slope lines for its mating external thread.

Schematic and simplified internal-thread representations recommended by the ASA for threads under 1 in. in diameter are seen in Fig. 12-9. If

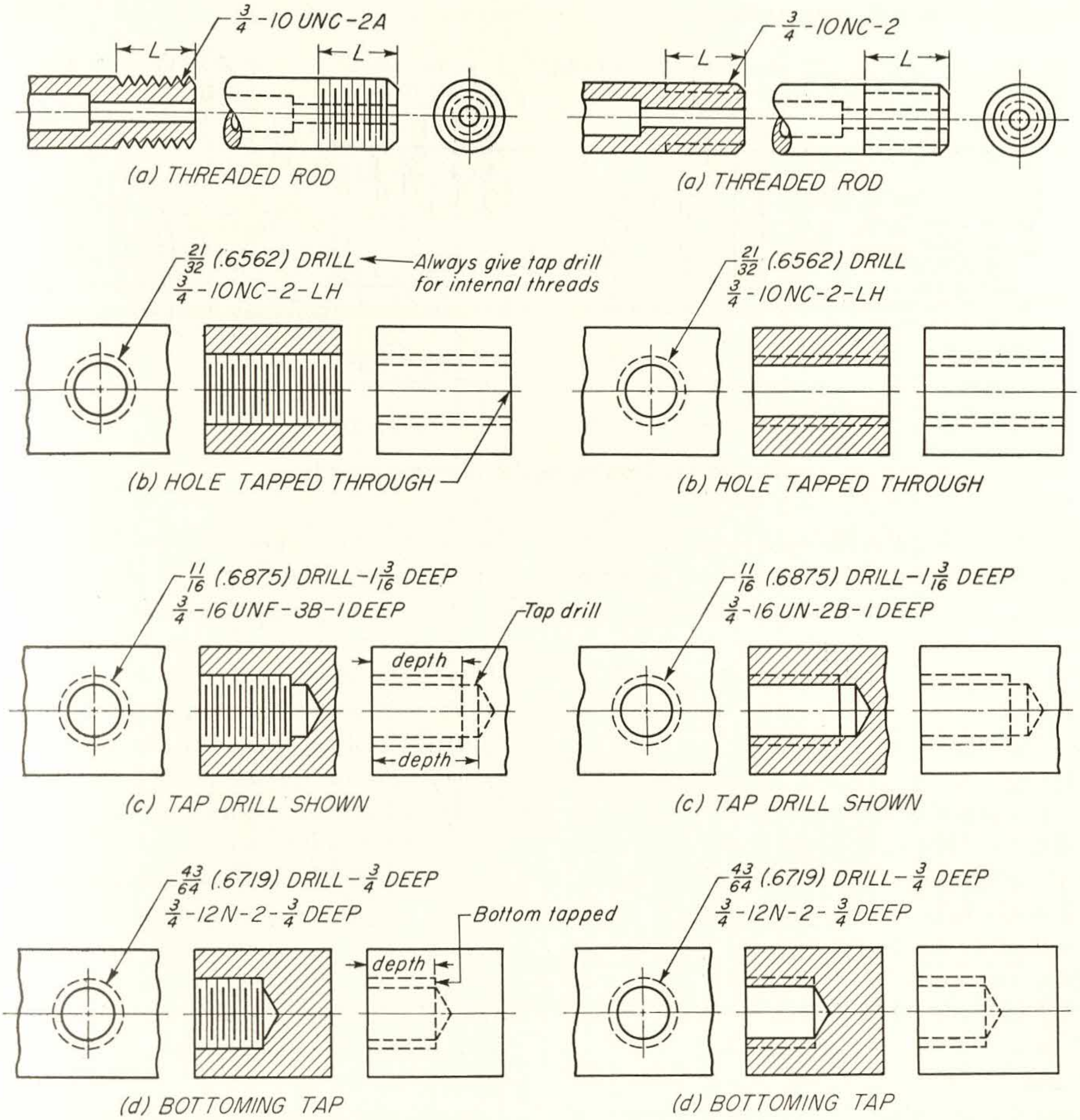

$\frac{3}{4}$-10 UNC-2A
L
L
(a) THREADED ROD
$\frac{3}{4}$-10NC-2
L
L
(a) THREADED ROD
$\frac{21}{32}$ (.6562) DRILL
$\frac{3}{4}$-10NC-2-LH
Always give tap drill for internal threads
(b) HOLE TAPPED THROUGH
$\frac{21}{32}$ (.6562) DRILL
$\frac{3}{4}$-10NC-2-LH
(b) HOLE TAPPED THROUGH
$\frac{11}{16}$ (.6875) DRILL-1$\frac{3}{16}$ DEEP
$\frac{3}{4}$-16 UNF-3B-1 DEEP
Tap drill
depth
depth
(c) TAP DRILL SHOWN
$\frac{11}{16}$ (.6875) DRILL-1$\frac{3}{16}$ DEEP
$\frac{3}{4}$-16 UN-2B-1 DEEP
(c) TAP DRILL SHOWN
$\frac{43}{64}$ (.6719) DRILL-$\frac{3}{4}$ DEEP
$\frac{3}{4}$-12N-2-$\frac{3}{4}$ DEEP
Bottom tapped
depth
(d) BOTTOMING TAP
$\frac{43}{64}$ (.6719) DRILL-$\frac{3}{4}$ DEEP
$\frac{3}{4}$-12N-2-$\frac{3}{4}$ DEEP
(d) BOTTOMING TAP

Fig. 12-9. Schematic and simplified representation of threads.

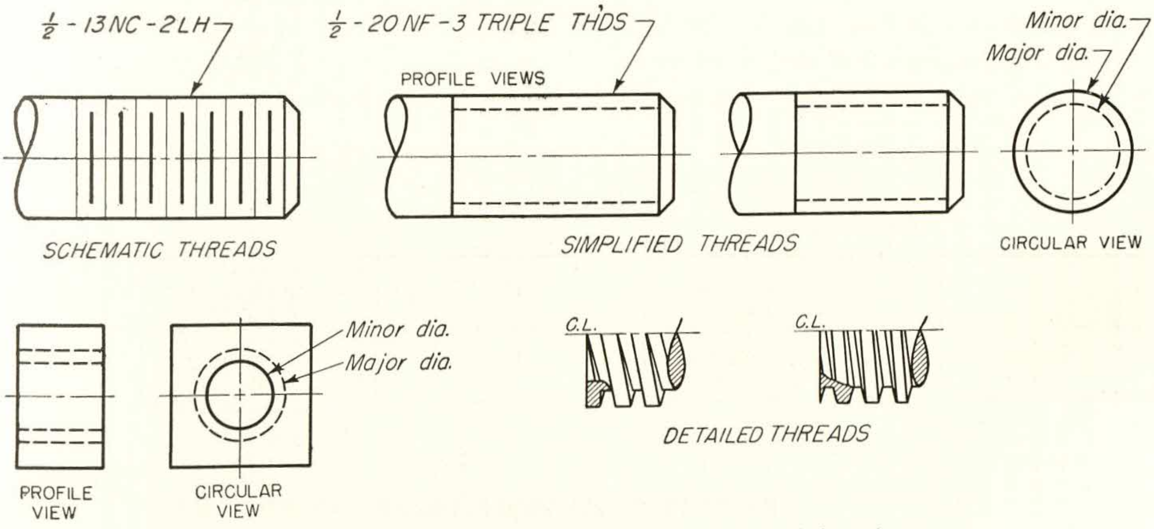


Fig. 12-10. Representation of internal and external threads.

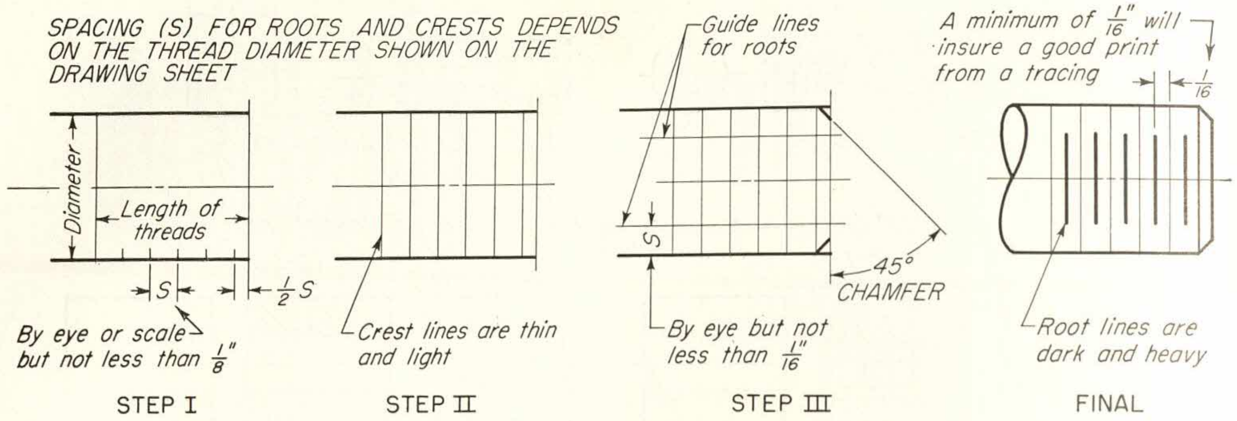

SPACING (S) FOR ROOTS AND CRESTS DEPENDS ON THE THREAD DIAMETER SHOWN ON THE DRAWING SHEET
Diameter
Length of threads
S
1/2 S
By eye or scale but not less than 1/8"
Crest lines are thin and light
Guide lines for roots
S
45° CHAMFER
By eye but not less than 1/16"
A minimum of 1/16" will insure a good print from a tracing
1/16
Root lines are dark and heavy
STEP I
STEP II
STEP III
FINAL

Fig. 12-11. Drawing regular schematic threads.

two or more mating threaded pieces are drawn in section, a combination of the three types of representation (detailed, schematic, and simplified) may be used as shown in Fig. 12-14.

12-11. American Standard threads. The American Standard threads (the same as the United States Standard) consist of five series of threads having the same shape, or form, but a different pitch (number of threads to the inch) for a given diameter. The basic angle between the sides of the thread measured parallel to the axis is 60°. The difference between the V form and the American Standard is seen in the flattening of the crests and roots (see Fig. 12-3). The width of the flat roots and crests in the American Standard thread should be about one-eighth the pitch.

The five American Standard thread series are the coarse-thread series, the fine-thread series, the 8-pitch, the 12-pitch, and the 16-pitch thread series (see Table 5 in the Appendix). The *coarse-thread series* is widely used in industry and is suitable for ordinary holding purposes. It is designated by the abbreviation NC, which stands for National (or American) coarse. The *fine-thread series* has more threads per inch and is better adapted to requirements demanding ease of assembly, great strength, and resistance to vibration. It is designated by the abbreviation NF. The *8-pitch series* (8 threads to the inch, diameters 1 to 6 in.) is used primarily on bolts to give high tension to sealing surfaces such as a cylinder or a boiler head. It is designated by the symbols 8N, where the numeral represents the number of threads per inch and N stands for National. The *12-pitch series* (12 threads to the inch, diameters ½ to 6 in.) is mainly used for thin parts in machine construction. It is designated by the symbols 12N. The *16-pitch series* (16 threads to the inch, diameters ¾ to 4 in.) is used on forms such as bearing retainers and collars. It is designated by the symbols 16N.

12-12. SAE extra-fine thread series. The Society of Automotive Engineers has adopted a thread that has the same form as the American thread yet seems to be better adapted to the needs of the automobile industry for very close adjustments and vibrationless adherence. This series,

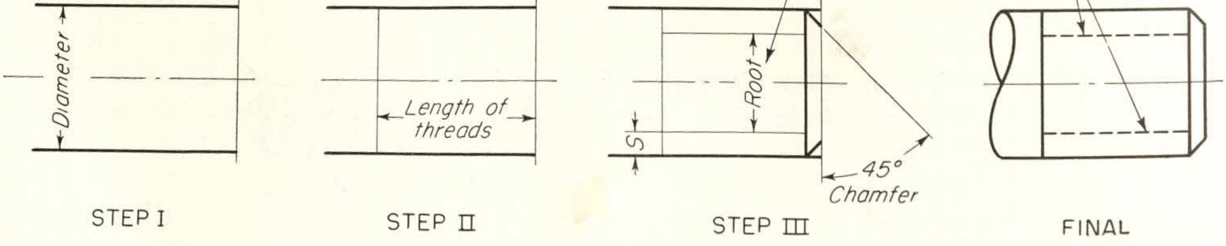


Fig. 12-12. Drawing simplified threads.

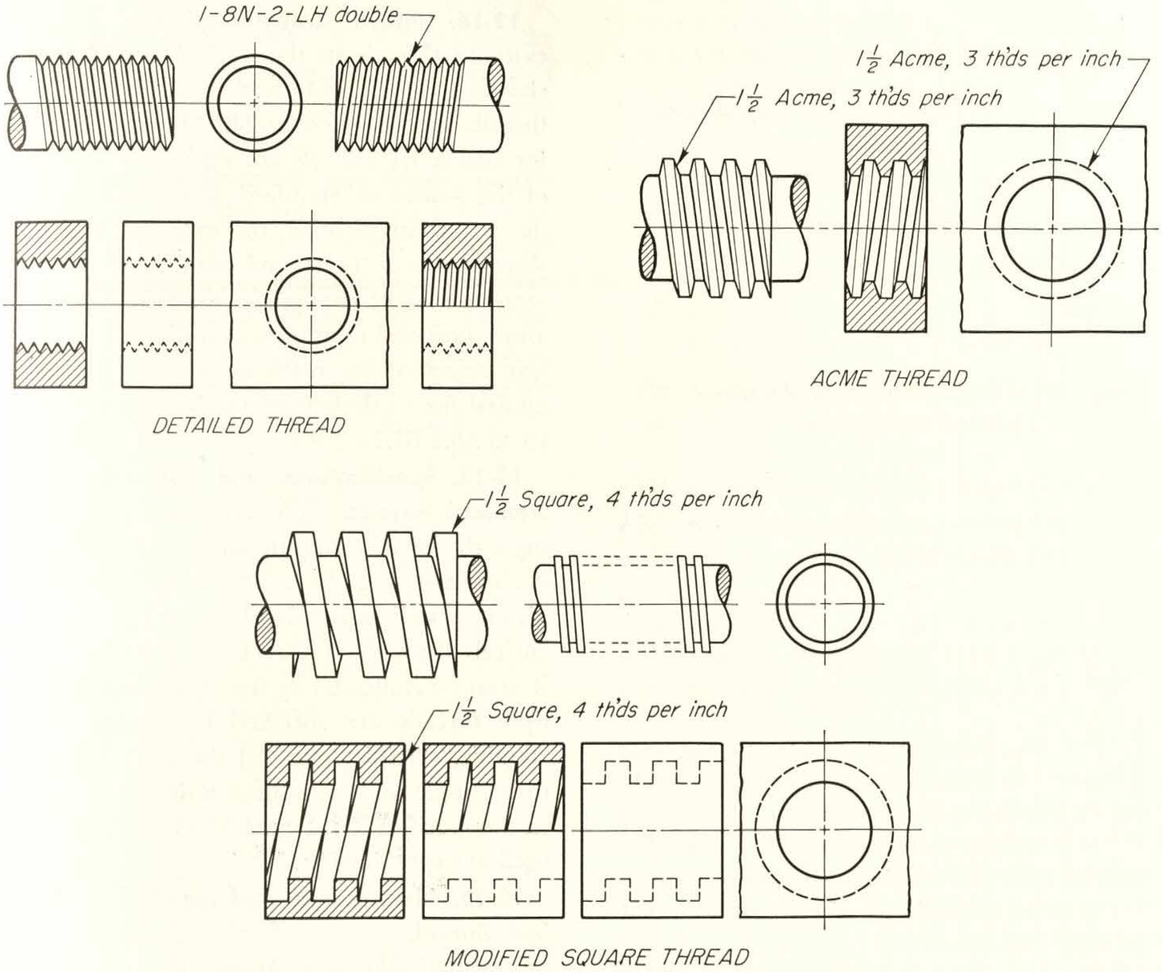

1-8N-2-LH double
DETAILED THREAD
1½ Acme, 3 th'ds per inch
1½ Acme, 3 th'ds per inch
ACME THREAD
1½ Square, 4 th'ds per inch
1½ Square, 4 th'ds per inch
MODIFIED SQUARE THREAD

Fig. 12-13. Representation of threads in section. (ASA Z14.1—1946.)

designated by the abbreviation EF, provides for a greater number of threads than the American Standard for any of the given diameters (see the table in the Appendix).

12-13. American Standard screw-thread fits.

Four types of screw-thread fits have been standardized by the ASA. A "fit" refers to the manner in which two mating threads, such as those on a nut

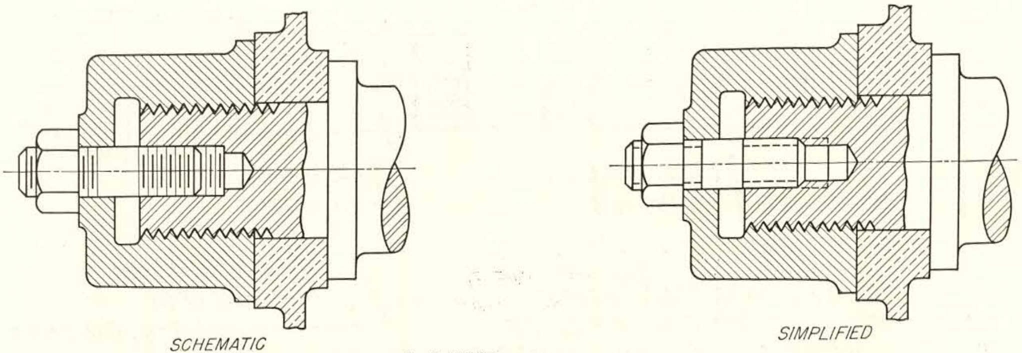


Fig. 12-14. Use of detailed, schematic, and simplified threads in assemblies.

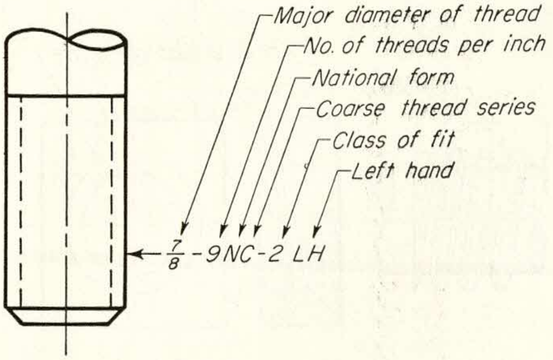


Fig. 12-15. Explanation of an American Standard thread note.

and bolt, are brought together into assembly. The following descriptions are taken from the ASA Standards (ASA B1.1—1935).

Class 1 Fit. Recommended only for screw-thread work where clearance between mating parts is essential for rapid assembly and where shake or play is not objectionable.

Class 2 Fit. Represents a high quality of commercial thread product and is recommended for the great bulk of interchangeable screw-thread work.

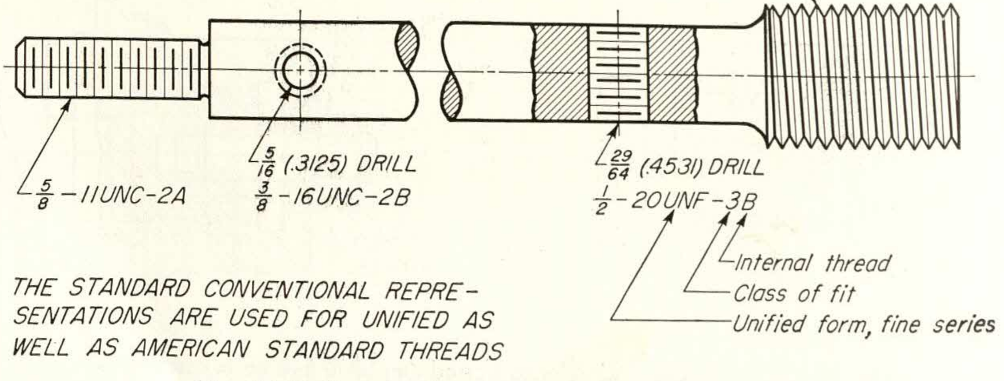
Class 3 Fit. Represents an exceptionally high quality of commercially threaded product and is recommended only in cases where the high cost of precision tools and continual checking is warranted.

Class 4 Fit. Intended to meet very unusual requirements more exacting than those for which Class 3 is intended. It is a selective fit if initial assembly by hand is required. It is not, as yet, adaptable to quantity production.

12-14. Unified screw-thread fits. The fits for external threads in the unified thread system are classified as 1A, 2A, and 3A. Fits for internal threads are classified as 1B, 2B, and 3B. The fits for classes 1A and 1B are similar to the class 1 fit of the American Standard. Classes 2A and 2B are the fits recommended for external and internal threads, screws, bolts, and nuts. Classes 3A and 3B represent slight changes in the relationship of the allowances and tolerances as indicated in the American Standard fits in the same class. (For adapting unified fits to designs of unified screw threads, refer to ASA B1.1—1949.)

12-15. Specifications and notes for American Standard threads. The approved method for giving a thread note for an American Standard thread is shown in Fig. 12-9. The tap-drill size must be given, as well as the depth if the hole does not go entirely through. If a left-hand thread is called for, it must be indicated by the abbreviation LH. Multiple threads are specified by adding the words "double," "triple," etc. All threads are understood to be single and right-hand unless otherwise noted in the specification. Figure 12-15 explains the terms used in a specification.

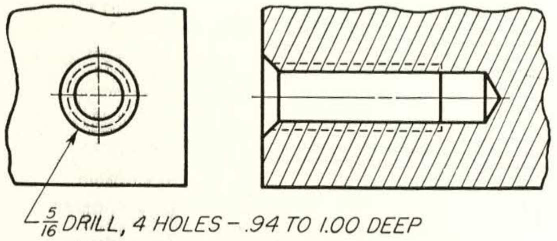
12-16. Identification and specification for a unified thread. A thread of the unified system is represented like any American Standard thread, and its specification is the same except that the U is added to the thread series and the letter A is added to indicate an external thread and the letter B to indicate an internal thread (see Fig. 12-16).



THE STANDARD CONVENTIONAL REPRESENTATIONS ARE USED FOR UNIFIED AS WELL AS AMERICAN STANDARD THREADS

Fig. 12-16. Representing and specifying unified threads.

Figure 12-17 shows a more precise form of (an internal) thread note. Here the countersink, the pitch diameter of the threads, and the minimum depth of full threads have been added to the ordinarily required information.

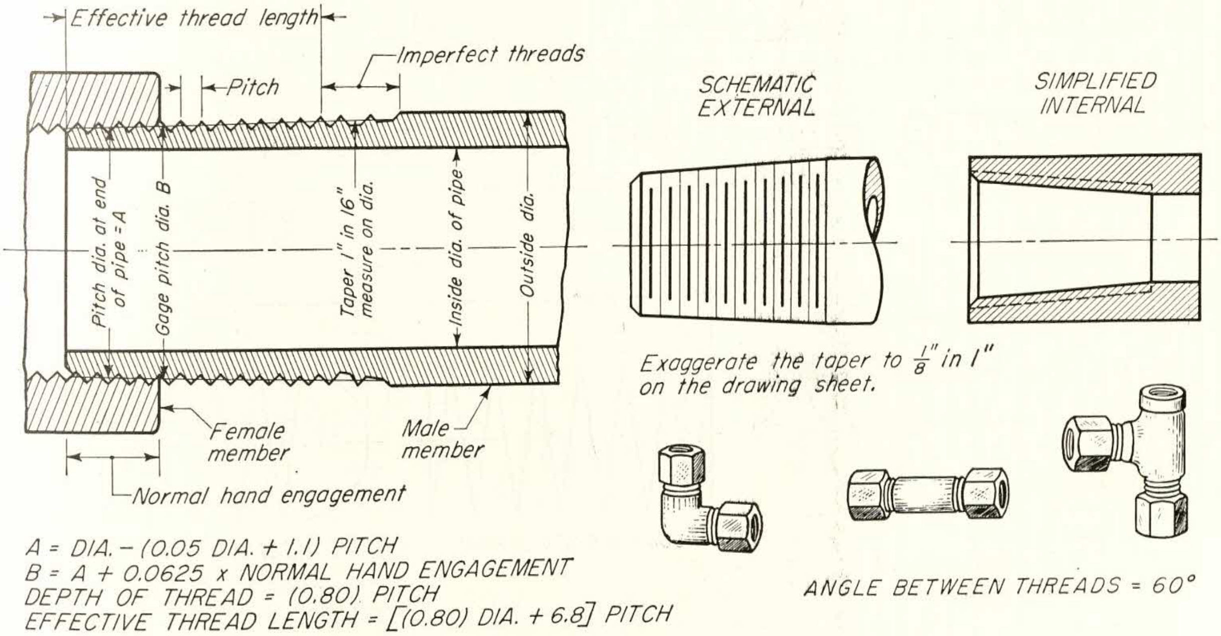


$\frac{5}{16}$ DRILL, 4 HOLES – .94 TO 1.00 DEEP
90° C'S'K TO .40 – .42 DIA
$\frac{3}{8}$ –16 UNC –2B
PD .3344 – .3401
.62 MIN DEPTH OF FULL THREAD

Fig. 12-17. Precise dimensioning of threads (usually for interchangeable manufacture). (*From tentative ASA Standards.*)

12-17. American Standard pipe-thread specifications and notes. The American Standard pipe threads are of two forms, the tapered threads and the straight threads. The number of threads per inch, the angle between threads (60°), and the depth of the threads are the same in both forms, their only difference being that the threads on the straight form are cut parallel to the axis of the pipe. The threads are shown on the drawing in the same manner as for the regular American Standard threads, that is, either detailed or by use of the schematic or simplified representations (see Fig. 12-18). The taper is drawn only when this feature is to be emphasized, since the taper is indicated in the thread note. If the taper is shown, it should be exaggerated on the drawing sheet. As shown in Fig. 12-19, the thread note always gives the nominal diameter of the thread and is followed by the letters NPT (National pipe taper) or NPS (National pipe straight). As a general rule, pipe threads should be shown in the schematic or simplified style; the detailed treatment is used only when threads are larger than 1 in. in diameter or are to be shown in assembly with other parts. For data on pipe threads of various diameters, see Table 27 in the Appendix.

12-18. Helical springs. The windings of torsion, extension, and compression springs follow the same helical path as that of the single screw thread. In large representations, springs are shown detailed in their free length and with the type of ends required. When sectioned, the cut portion is filled in solid black for a small spring and sectionlined for a large one. The procedure for drawing a spring is the same as that for drawing a single right-hand screw thread. The pitch distances are set off along the line of the outer diameter, and the coils are sloped leaning toward the left at an angle equal



Exaggerate the taper to $\frac{1}{8}$" in 1" on the drawing sheet.

ANGLE BETWEEN THREADS = 60°

A = DIA. – (0.05 DIA. + 1.1) PITCH
B = A + 0.0625 x NORMAL HAND ENGAGEMENT
DEPTH OF THREAD = (0.80) PITCH
EFFECTIVE THREAD LENGTH = [(0.80) DIA. + 6.8] PITCH

Fig. 12-18. Pipe-thread information.

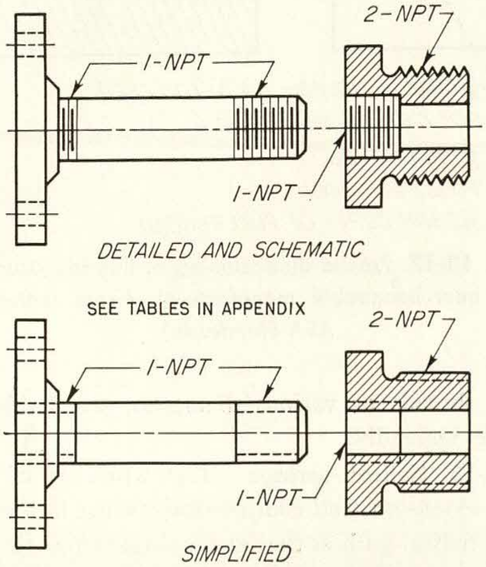


Fig. 12-19. Pipe-thread representation and specifications.

to one-half the pitch. Small springs are represented schematically in assembly drawings, as shown in Fig. 12-20.

The specifications required for a spring are its free length, size and shape (round or square) of the wire, inside diameter (if working on a shaft), outside diameter (if working free or in a hole), number of coils (or pitch), material from which the spring is to be made, and style of ends. See specifications as shown in Fig. 7-30 and Prob. 12-19.

12-19. American Standard bolts and nuts. Three series of bolts and nuts have been approved by the ASA, as follows:

1. *Regular-series boltheads and nuts.* This series is recommended for most uses.

2. *Heavy-series boltheads and nuts.* This series is designed to give a greater bearing surface for a wrench and greater clearance between bolthead and hole.

3. *Light-series nuts.* The nuts in this series are smaller across flats than the nuts in the regular series. They are usually fine-threaded and are designed to save material and weight.

Nuts and bolts are also classified as *unfinished, semifinished* (finish on bearing surface only), and

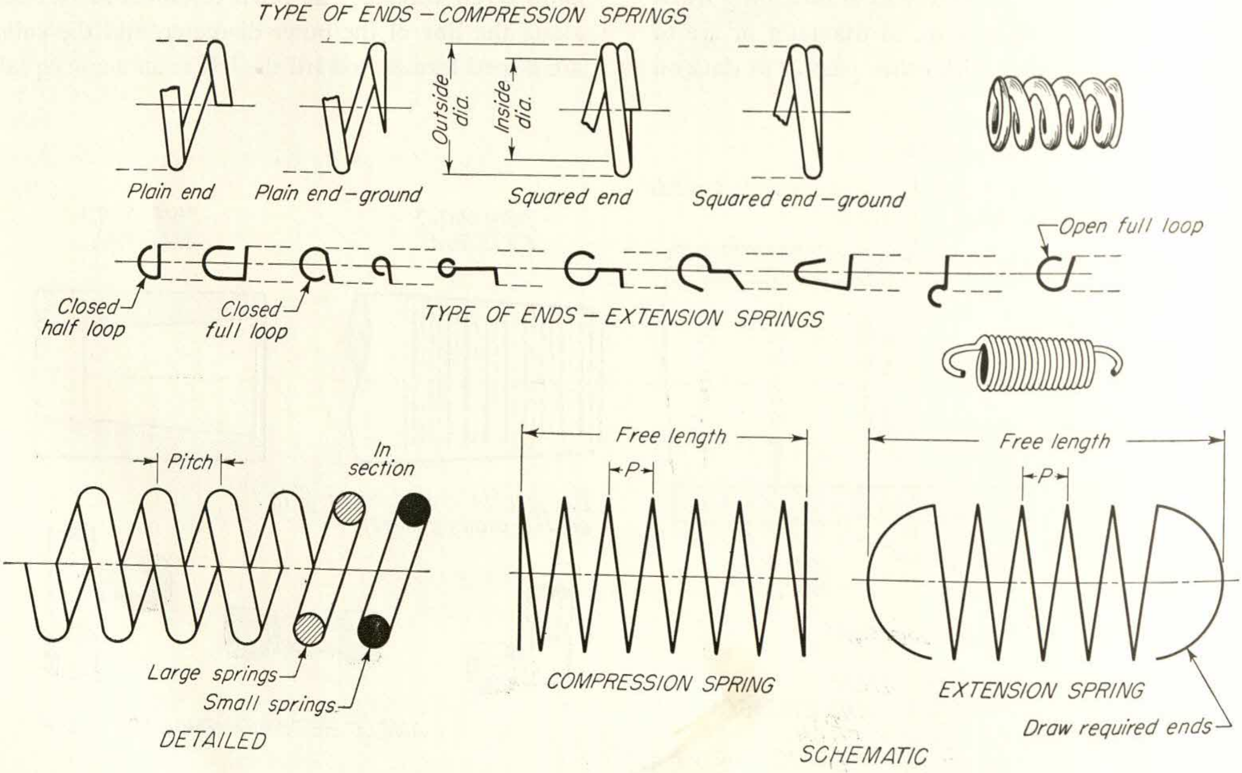


Fig. 12-20. Drawing helical springs.

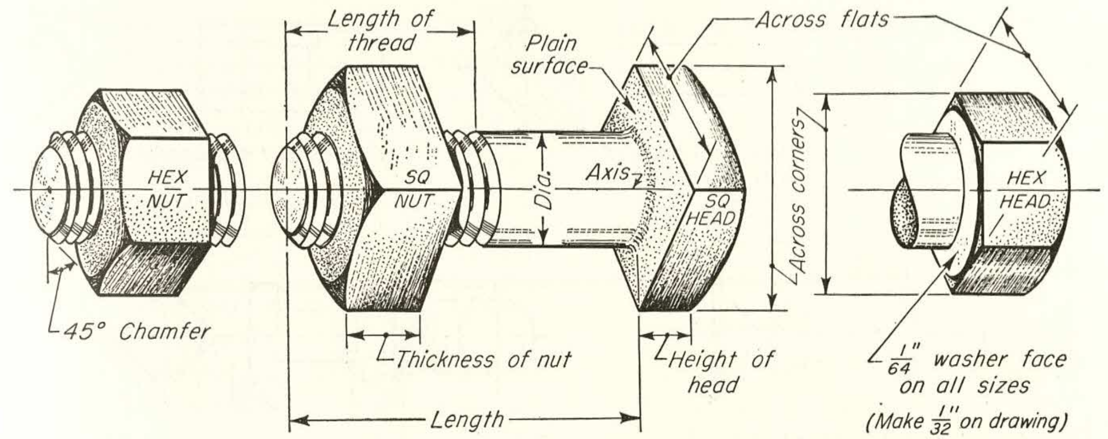
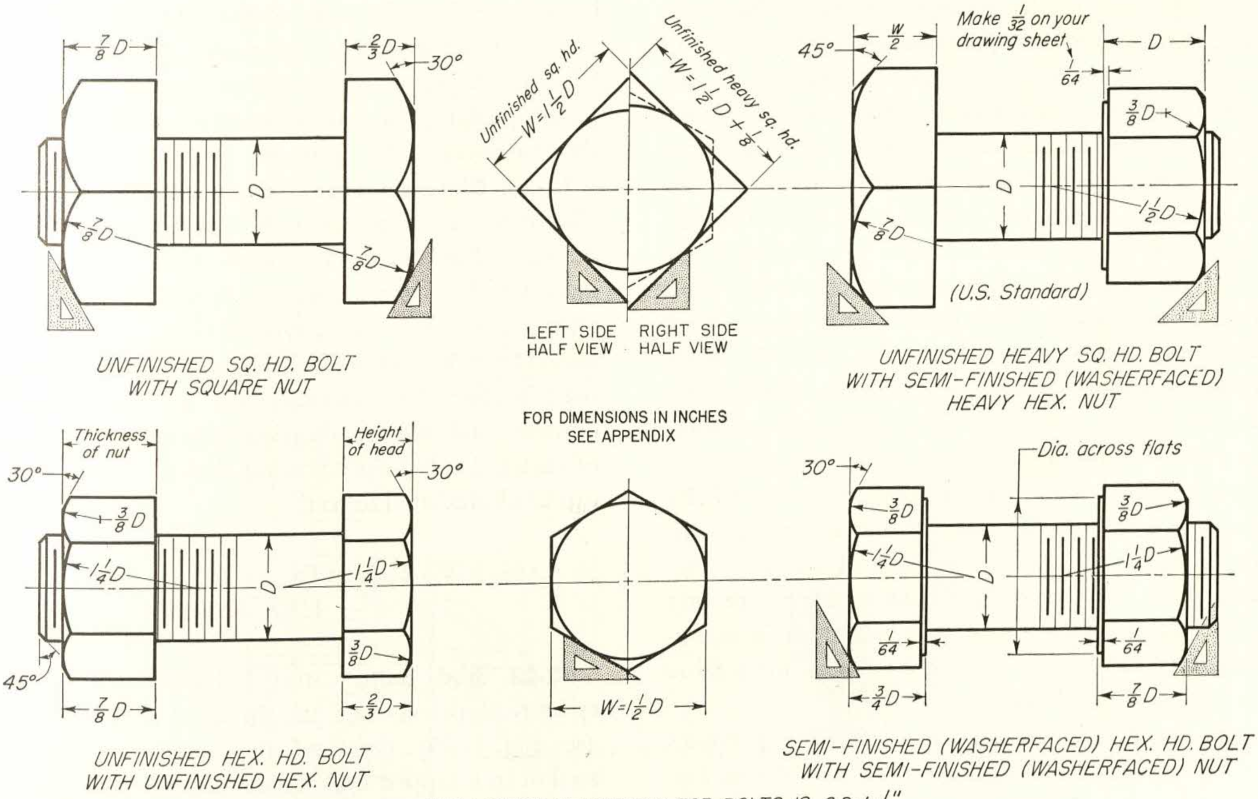


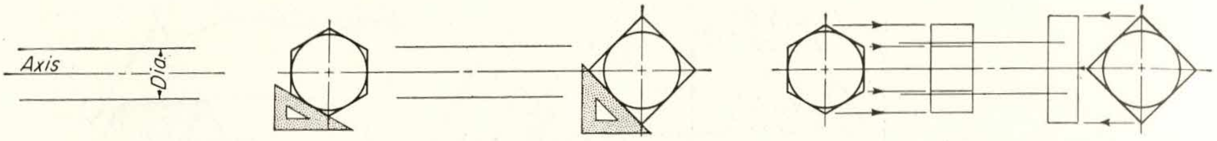
Fig. 12-21. American Standard bolts and nuts.

finished (finished all over). Semifinished and finished nuts and bolts may have a washerface machined on the bearing-surface side of the bolthead or nut to lessen the stress at the corners (see Fig. 12-21). A washerface is 1/64 in. thick, and its diameter is equal to the distance across the flats of the head or nut. This 1/64 in. is always included in the height of the head or thickness of the nut. The thickness of finished, semifinished, and unfinished nuts is the same for the same thread diameters and finish (except for the United States Standard bolt). However, the heights of the unfinished hexagonal head, the finished hexagonal head, and the square head vary in size for the same thread diameter and finish (see Fig. 12-22). To avoid confusion, all nuts and boltheads, both square and hexagonal, are presented as drawn across corners in all views on the drawing sheet (see Fig. 8-28).


7/8 D
2/3 D
30°
D
7/8 D
7/8 D
UNFINISHED SQ. HD. BOLT WITH SQUARE NUT
Unfinished sq. hd. W=1 1/2 D
Unfinished heavy sq. hd. W=1 1/2 D + 1/8
LEFT SIDE HALF VIEW
RIGHT SIDE HALF VIEW
45°
W/2
Make 1/32 on your drawing sheet
1/64
D
3/8 D
D
1/2 D
7/8 D
(U.S. Standard)
UNFINISHED HEAVY SQ. HD. BOLT WITH SEMI-FINISHED (WASHERFACED) HEAVY HEX. NUT
FOR DIMENSIONS IN INCHES SEE APPENDIX
Thickness of nut
Height of head
30°
30°
3/8 D
1 1/4 D
D
1 1/4 D
3/8 D
45°
7/8 D
2/3 D
W=1 1/2 D
UNFINISHED HEX. HD. BOLT WITH UNFINISHED HEX. NUT
Dia. across flats
30°
3/8 D
1 1/4 D
D
1/64
3/8 D
1 1/4 D
1/64
3/4 D
7/8 D
SEMI-FINISHED (WASHERFACED) HEX. HD. BOLT WITH SEMI-FINISHED (WASHERFACED) NUT

MINIMUM LENGTH OF THREAD FOR BOLTS IS 2D + 1/4"
Never show finish marks (∫, V) on nuts and bolts

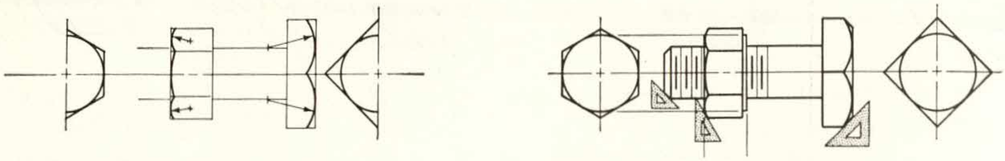
Fig. 12-22. Formulas for drawing bolts and nuts.



Draw axis and major diameter
STEP I

Draw nut and head in related views
STEP II

Project nut and head to profile view
STEP III



Draw arcs in nut and head. For suggested arc radii see fig. 12-22
STEP IV

Draw threads on bolt and chamfers on nut, head, and at end of thread if required. Washerface if required.
FINAL

Fig. 12-23. Steps in drawing a bolt and nut.

12-20. Formulas for drawing bolts and nuts. In commercial practice, standard bolts and nuts need not be shown on the detail sheet. However, they are shown on assembly drawings, where they are encountered very frequently. To save time, the draftsman follows a procedure that enables him to scale all significant dimensions of a bolt and nut in proportion to the given diameter of the bolt. The dimensions of the features of the American Standard bolts and nuts shown in Fig. 12-22 are given in terms of the bolt diameters. Note that the chamfer angle at the top of the heavy series (old United States Standard) bolthead is 45°, and the chamfer on the lighter square and hex heads and nuts is 30°. If the bolt diameter is less than 1 in., the head and nut chamfers may be omitted. The lengths of bolts are not standardized. Square-head bolts may range in length from ½ to 24 in. Hex-head bolts range from ½ to 12 in. in length. (For thread lengths, see tables in the Appendix.) When precise measurements are required, the actual dimensions in inches of the various features of bolts and nuts, such as the distance across flats, the distance across corners, the length of the bolt, the length of the thread, the chamfers, etc., for any given diameter of thread may be found in manufacturers' catalogues. See the Appendix for a table of typical dimensions.

12-21. Drawing a bolt and nut. For purposes of completeness in demonstration, the bolt in Fig. 12-23 has a square head and a hex nut. Start by laying out the major diameter, axis, and length of the bolt (bolt length is measured from the under-surface of the head to the end of the shaft). Draw the adjacent views (contours) of the hex nut and square head, as shown in Step II. Note that they are drawn on vertical corners and that the circles representing the distances across flats are inscribed. Complete the representation as suggested in Steps III, IV, and V. If only the profile view of the bolt is desired, the adjacent hex-nut and square-head views may be drawn as half views, as seen in Step IV, and the required construction lines projected to the profile. The half views may be erased after they have served their purpose.

12-22. Dimensioning and specifying a bolt. The manner in which a bolt is dimensioned is shown in Fig. 12-24. The specification requires the diameter, length, number of threads to the inch, series, class of fit, finish, type of head, and type of nut. The dimensions are shown on the detail drawing. In assembly drawings, the dimensioning is omitted, and the specification is given in the bill of materials. The specification shown in Fig. 12-24 can be abbreviated to read

½ × 1¾ UNC SEMI-FIN
HEX HD BOLT & NUT

12-23. Stud bolts. Stud bolts, or studs, are cylindrical pieces that are threaded at both ends (see Fig. 12-25). One end, the stud end, is for insertion in a tapped hole that is slightly longer than the thread on the stud. The other end receives one or two nuts—the second, if used, locking the first in place. Studs are used for holding cylinder heads, covers, etc., in place. In the automotive industry, studs vary from 5/16 to 3/4 in. in diameter, and the lengths beyond the stud-end threading range from 5/8 to 4 3/4 in. The stud ends (tapped-hole ends) have American Standard (or unified) coarse threads; American Standard (or unified) fine threads are cut on the outside, or nut, ends. The end chamfers are 45° and are 1/32 to 3/32 in. in length. Study the illustration for further information on drawing procedure.

Figure 12-26 illustrates the manner in which a stud with unified threads is dimensioned when shown as a detail (not in assembly). The specification serves in place of dimensioning when the stud is shown in an assembly drawing. (For American Standard studs, make the thread specification read like the sample shown in Fig. 12-24.) The specification in Fig. 12-26 can be abbreviated by giving only the diameter and length of the stud,

5/8 × 2 3/8 STUD

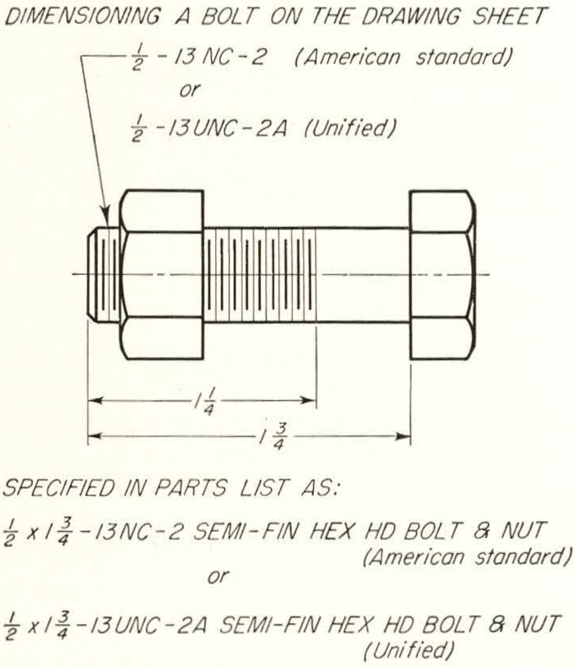
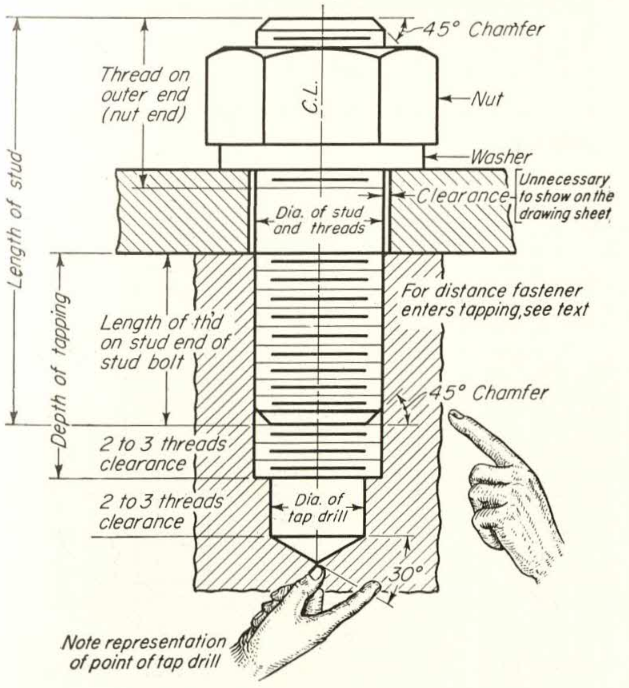

DIMENSIONING A BOLT ON THE DRAWING SHEET
1/2 - 13 NC - 2 (American standard)
or
1/2 - 13UNC - 2A (Unified)
1 1/4
1 3/4
SPECIFIED IN PARTS LIST AS:
1/2 x 1 3/4 - 13NC - 2 SEMI-FIN HEX HD BOLT & NUT (American standard)
or
1/2 x 1 3/4 - 13UNC - 2A SEMI-FIN HEX HD BOLT & NUT (Unified)

Fig. 12-24. Dimensioning and specifying a bolt.

12-24. Length of engagement of threads. In general, for any threaded fastener the length of engagement with the component part may be represented empirically (see Fig. 12-27). When both components are made of steel, the length E is equal to the nominal diameter of the threads D. For steel threads assembling into cast iron, brass, or bronze, E is equal to $1\frac{1}{2}D$. For steel threads assembling into aluminum, zinc, or plastic, E is equal to $2D$.

12-25. Cap screws. Cap screws are fasteners that hold together two pieces by passing through a nonthreaded hole in one piece and screwing into a tapped hole in the other. There are five basic types of cap screws: the hex head, the flat head, the round head (formerly button head), the fillister head, and the socket head (see Fig. 12-28). Cap screws are used when accurate fits and a fine appearance are desired. The hex-head cap screws are usually finished all over and are provided with a washerface 1/64 in. thick that has a diameter equal


45° Chamfer
Thread on outer end (nut end)
C.L.
Nut
Washer
Unnecessary to show on the drawing sheet
Clearance
Dia. of stud and threads
Length of stud
Depth of tapping
Length of thd on stud end of stud bolt
For distance fastener enters tapping, see text
45° Chamfer
2 to 3 threads clearance
2 to 3 threads clearance
Dia. of tap drill
30°
Note representation of point of tap drill

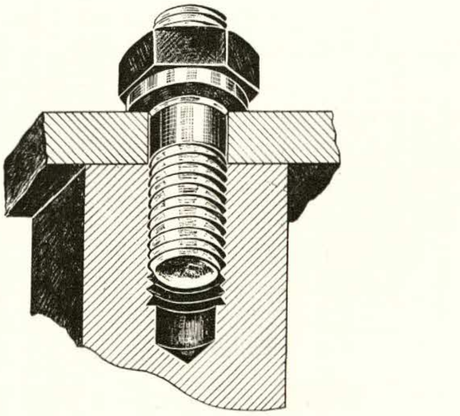


Fig. 12-25. Stud bolt.

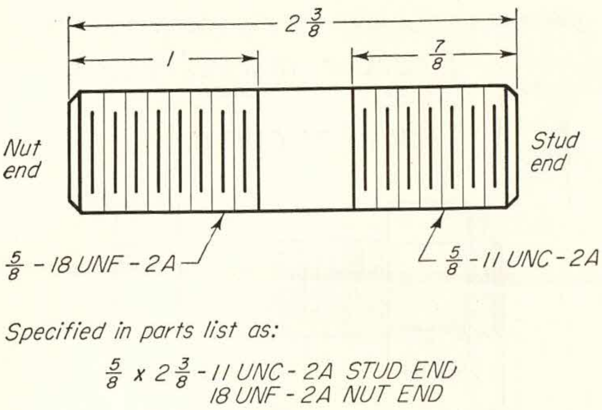


Fig. 12-26. Dimensions and specification for stud with unified threads.

to the distance across flats. The other types of cap screws are usually semifinished, although they are also available finished all over. Cap screws may be had with either unified or National coarse or fine threads. In the unified series, the fit is usually class 2; in the National series, it is customarily class 3.

Finished cap screws are produced to conform with ASA-approved proportions and are made in body diameters ranging from 1/4 to 1 1/4 in. (except socket-head cap screws, which are made in diameters of 0.0860 in. to 1 1/2 in.). Table 8 in the Appendix lists the body, head, and slot dimensions for cap screws. The lengths for cap screws have not been standardized.

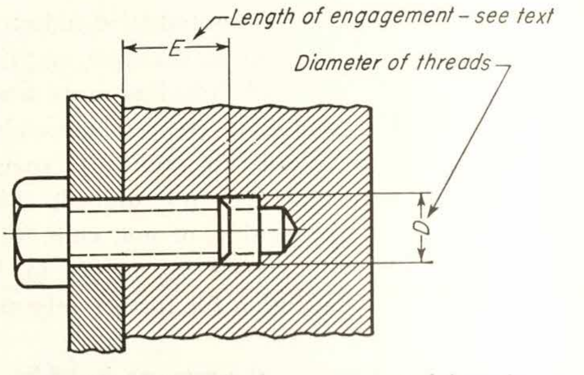


Fig. 12-27. Length of engagement of threads.

For thread lengths on cap screws, see tables in the Appendix.

A cap screw is specified by giving its diameter, length, number of threads per inch, thread series, fit, type of head, and designation, as in the following example,

9/16 × 3 1/4-12 UNC-2A FLAT HD CAP SCR

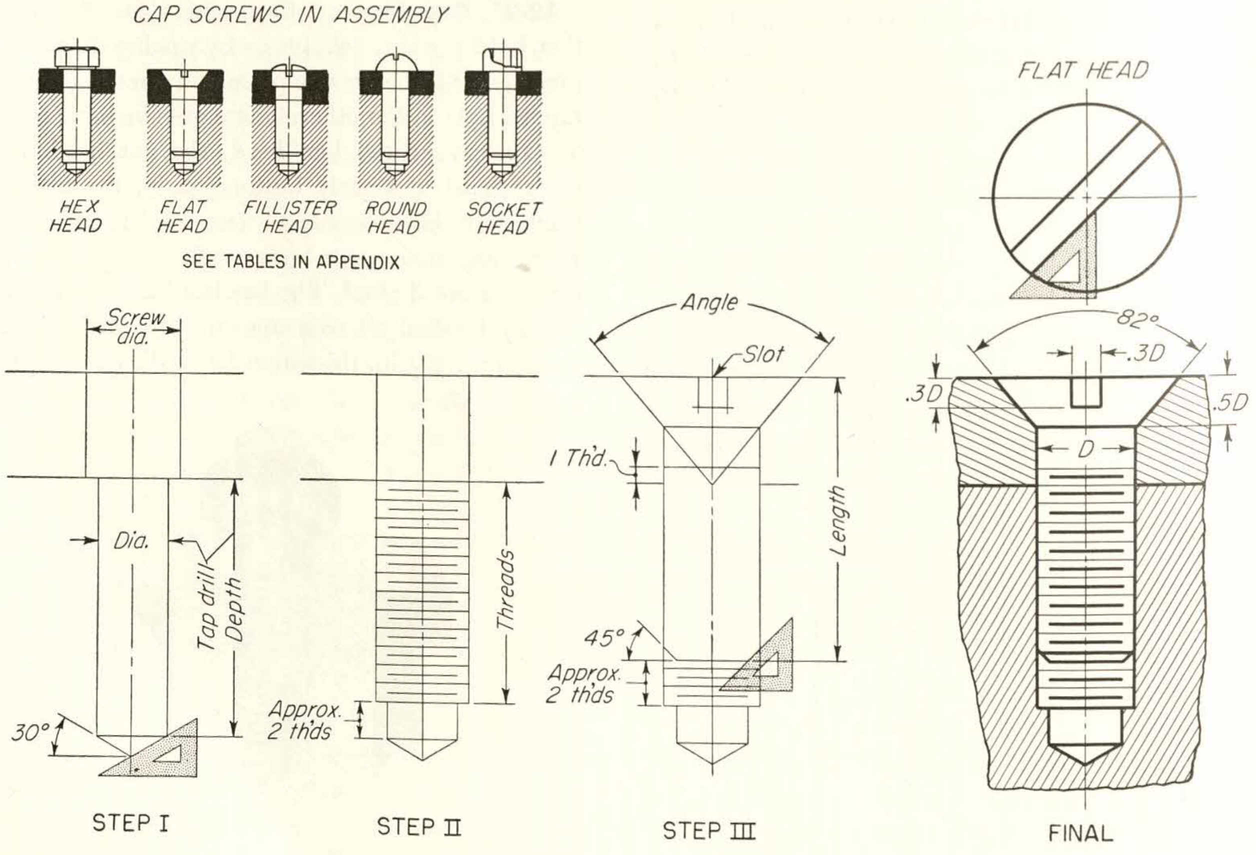


Fig. 12-28. Drawing cap screws and machine screws.

which can be further abbreviated to read

9/16 × 3¼ UNC FLAT HD CAP SCR

The formulas for drawing cap screws are shown in Figs. 12-28 and 12-29. Note in particular that the slots of the flat-head, round-head, and fillister-head cap screws are shown at a 45° angle in the circular views, regardless of true projection.

12-26. Machine screws. Machine screws are similar to cap screws, but they are generally smaller in diameter (0.060 to 0.750 in.). They are available with eight different types of heads, including all those found on cap screws. Unlike the cap screws, however, machine screws are rarely manufactured with the hex or socket heads. Machine screws are used primarily for light-duty work. They are available in either the unified or National coarse-thread or fine-thread series, and are usually class 2 fit. Machine screws may be drawn with the same formulas used for cap screws (see Figs. 12-28 and 12-29). Exact dimensions, types of heads, and other information about machine screws may be found in Table 9 in the Appendix.

A machine screw is specified by giving its diameter, the length, thread specification, fit, type of head, and designation. The following is an example,

No. 8 × ¾-32 UNC-2A OVAL HD MACH SCR

which may be further abbreviated to read

No. 8 × ¾ UNC OVAL HD MACH SCR

Although the lengths of both the cap screws and the machine screws have not been standardized, various manufacturers stock cap screws varying between ¼ and 6 in. long and machine screws ranging between ⅛ and 3 in. Nearly four-fifths of all machine screws are manufactured with coarse threads. See tables in the Appendix.

12-27. Locking devices. There are many types of locking nuts and other such devices available that are intended to prevent fastened parts from working loose under vibration (see Fig. 12-30). The commonest form of locking nut is the jam nut. It is hexagonal in shape, with a flat top chamfered at 30°. Its thickness is half its diameter. It is supplied semifinished and washerfaced or unfinished with a plain bearing surface. The slotted type of nut is assembled with a cotter pin. All slotted nuts are semifinished and are available in the regular, heavy, and light series. The tops are flat and chamfered. The castle nut is higher than the standard slotted nut. A wire or cotter pin is passed through the slot and through a hole in the shaft to prevent the nut from working loose on its mounting.

Standard plain and lock washers (Fig. 12-30) are used with regular standard nuts. These and special washers are used with cap screws and machine screws. Standard washers are specified by giving the type, inside diameter, outside diameter, and thickness (see Appendix for dimensions).

Several types of stop nuts are also available. These are manufactured with a semiplastic insert that acts as the locking device when the nut is tightened firmly in position.

The aero thread used in the airplane industry consists of a bronze or steel spring insert conforming to a standard thread which is placed in the tapped hole before the insertion of a cap screw or stud (see Fig. 12-31). The use of the spring insert affords a secure hold for the screw or stud in the soft aluminum alloys used in the airplane industry.

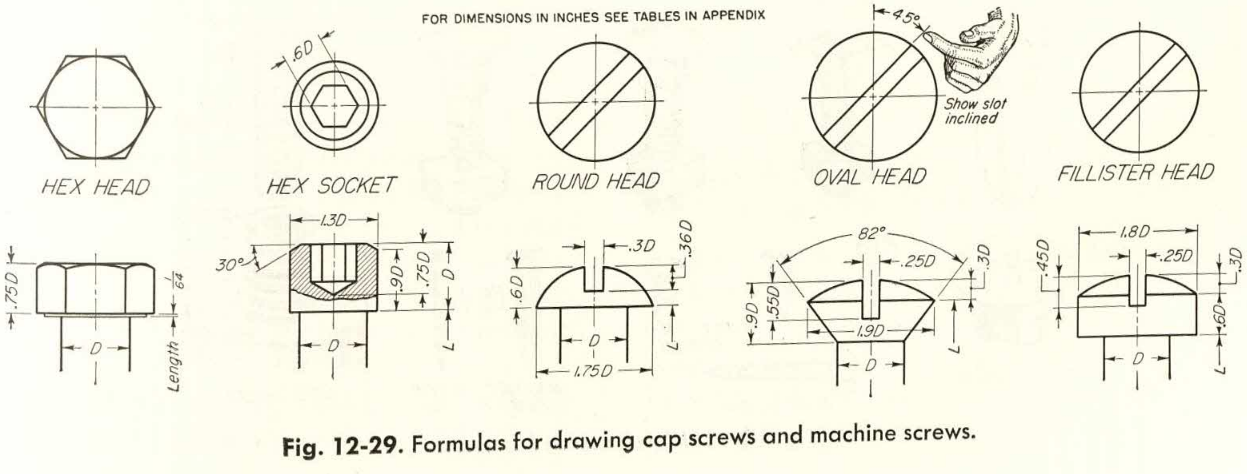

FOR DIMENSIONS IN INCHES SEE TABLES IN APPENDIX

Fig. 12-29. Formulas for drawing cap screws and machine screws.

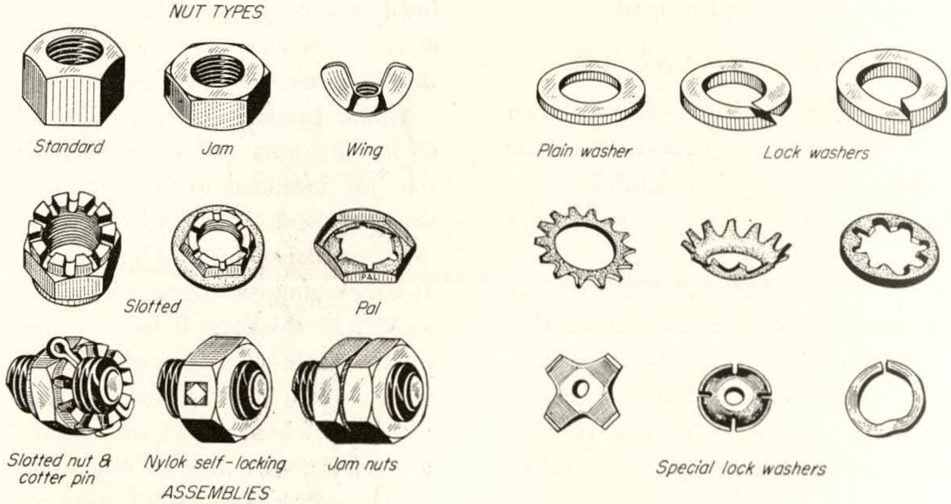


Fig. 12-30. Nut types and washers.

For information on the many other types of locking nuts and special screws, washers, etc., the draftsman may avail himself of the manufacturers' catalogues, which usually give the basic dimensions and specifications of their products.

12-28. Setscrews. Setscrews are mainly used to prevent rotary motion between two assembled parts, such as a pulley or collar mounted on a shaft. The setscrew is placed in a hole tapped in the hub of the pulley or collar and is then turned tight against the shaft. Setscrews are also used to make slight adjustments in the fit between mating parts and to permit changing locations of tools and other moving parts. In general, they are not used where the fixed parts may be subjected to heavy stresses or loads. The dangerous projecting-head types are being used less and less frequently, while the hollow or safety type has become more popular. The so-called "safety types" are either slotted or have square or hexagonal holes for receiving tightening wrenches. The American Standard setscrews range between $\frac{1}{4}$ and $1\frac{1}{2}$ in. in diameter. The lengths are not standardized. They are available in a variety of points and commonly have threads of the unified or American Standard coarse series. They are also available with fine threads. Formulas for representing setscrews are shown in Fig. 12-32.

A setscrew is specified by giving its diameter, length, number of threads per inch, thread series, fit, type of head, type of point, and designation, as shown in the following example,

$\frac{7}{16} \times 1\frac{1}{4}$-14 UNC-2A
H'DLESS OVAL PT SET SCR

which is further abbreviated to read

$\frac{7}{16} \times 1\frac{1}{4}$ UNC H'DLESS OVAL PT SET SCR

12-29. Keys and taper pins. Generally speaking, a key is a square, rectangular, or semicircular

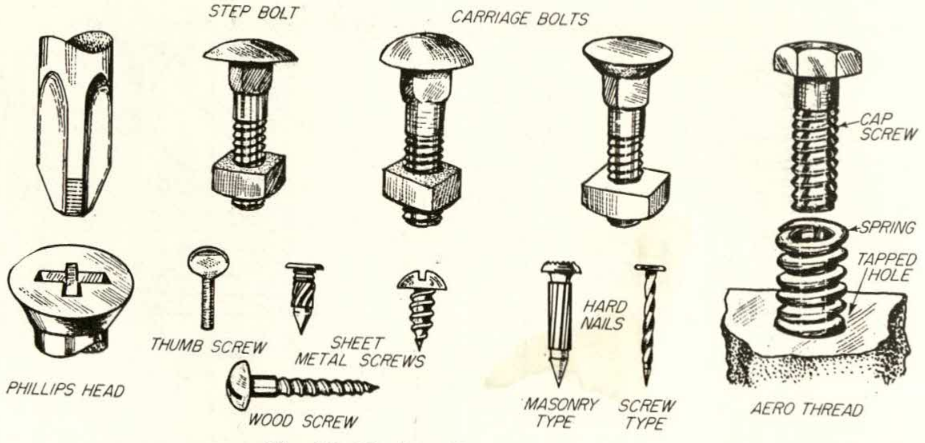


Fig. 12-31. Miscellaneous fasteners.

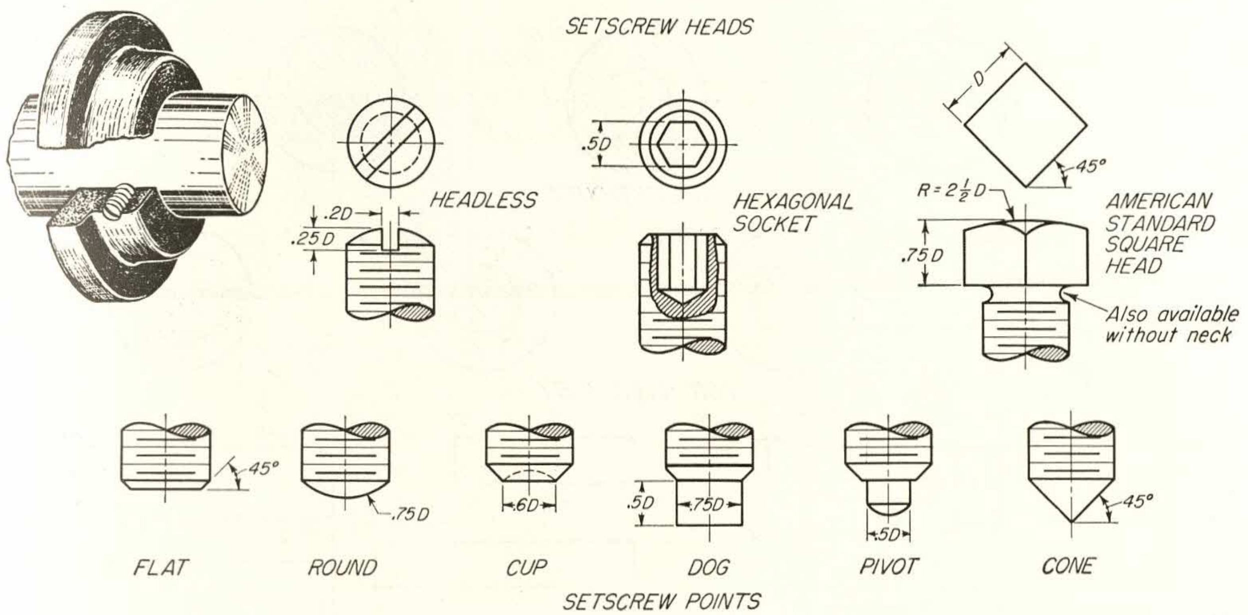


Fig. 12-32. Setscrews.

piece of steel which is inserted in a keyway or key seat cut in a shaft and pulley or gear and which, when in position, prevents relative rotary motion between the mating parts. In some cases, keys may prevent axial motion in the two parts. Typical key assemblies are in Figs. 12-33 and 12-34. The width of a sunk key is about one-fourth the diameter of the shaft. The thickness of a flat key is equal to about one-sixth the diameter of the shaft. For light duty and small parts, smaller keys may be used. American Standard square and flat keys have a taper ranging from $\frac{1}{8}$ to $\frac{3}{16}$ in. per ft.

A key that engages a slot formed in both the pulley and shaft is known as a "sunk key." The Woodruff key is an almost semicircular sunk key with either a round or a flat bottom (see Fig. 12-34). It is always specified by a number, the last two digits of which indicate the nominal diameter in eighths of an inch, while the one or two digits preceding the last two give the nominal width in thirty-seconds of an inch. Note from the illustration that the round key is not a complete semicircle, since the center for the circular arc of the key is located above the top edge. Keyways and key seats are cut by special cutters used on milling machines, on special key-slotting machines, or, in some particular cases, on broaching machines or planers and shapers.

The gib-head key (Fig. 12-34) is a sunk key which is placed in assembly with its head protruding far enough from the hub to permit the insertion of a tool for removal. The slot for the gib key must have an open end to permit assembly; for this reason, it is usually placed at the end of a shaft. Gib-head keys may be either saddle-shaped or flat. The saddle key is slightly curved on the underside and slightly tapered on top. The slot is cut into the hub, and when the key is forced into position, it grips the shaft through friction on that member. The flat key fits into a slot cut into the hub and rests on a slightly flat surface machined on the shaft. A feather or spline key is fixed to either the shaft or the hub. It permits axial motion while preventing rotary motion between the parts.

Keys and keyways should be shown to scale in assembly drawings. Only special designs or changes need be drawn on the detail sheets. Keys are specified in the manner illustrated by the following samples (see Appendix for dimensions):

No. 14 PRATT & WHITNEY KEY
No. 608 WOODRUFF KEY
$\frac{3}{8}$ SQ × 1$\frac{3}{4}$ KEY
$\frac{3}{8}$ × $\frac{1}{4}$ × 1$\frac{3}{4}$ FLAT KEY

Taper pins are driven into mating holes drilled in the hub and shaft (see Fig. 12-35). Sometimes referred to as round tapered keys, they are available in sizes ranging from 0.078 to 0.706 in. in diameter (at large end) and from $\frac{3}{8}$ to 6 in. in length. They are specified by code number, as follows:

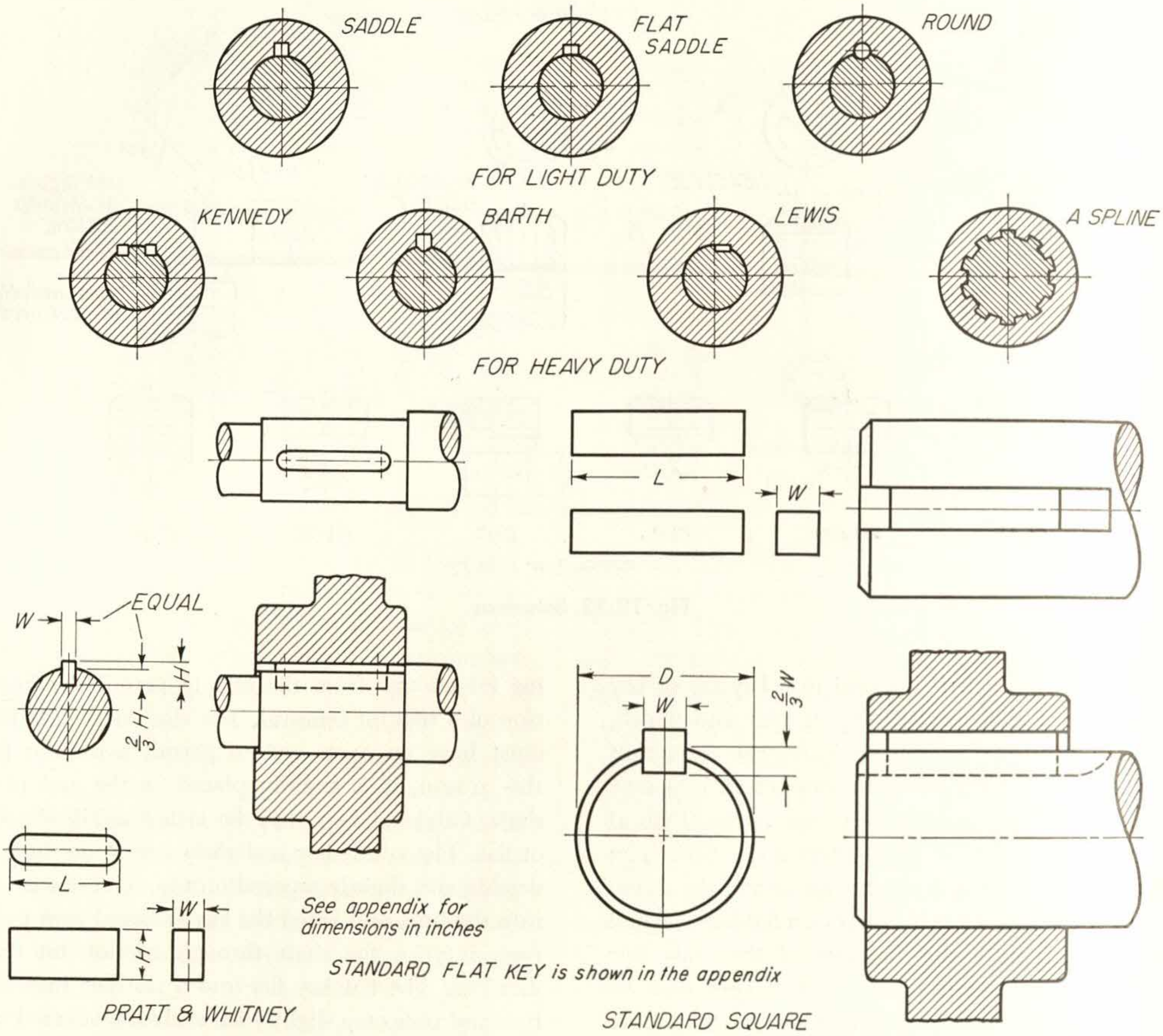


Fig. 12-33. Keys.

No. 4 STD TAPER PIN

Table 12 in the Appendix lists the standard taper pins, their diameters, and their minimum and maximum lengths, together with specifications indicating the proper taper pin to use for a given diameter of shaft. When taper pins are shown in assembly, the smaller end may be cut off at the required length.

12-30. Rivets. Rivets are permanent fasteners used to join metal parts. They may be made of mild steel, wrought iron, copper, or other metals or alloys. A rivet has a cylindrical body and a head that may be flat, spherical, or conical. When in assembly, the head at the other end may be formed in the same shape. There is always a clearance between the body of the rivet and the hole it enters. To fill this clearance after insertion and while the second head is being formed, the length beyond the plate should be equal to three-fourths the diameter for forming a flat or countersunk head and 1.3 to 1.7 times the diameter for forming the other types of heads. American Standard rivets are classified into two general sizes—large and small. Figure 12-36 illustrates the types of heads and shows the formulas used in drawing several of them. See Table 18 in the Appendix for formulas for small rivets.

12-31. Riveted joints. A lap joint is formed when one plate is placed over another and the two plates are riveted together by one or more rows of rivets. When the plates are held together by a cover plate or strap, they form a butt joint (see Fig. 12-36). If a lap joint is held together by a single row

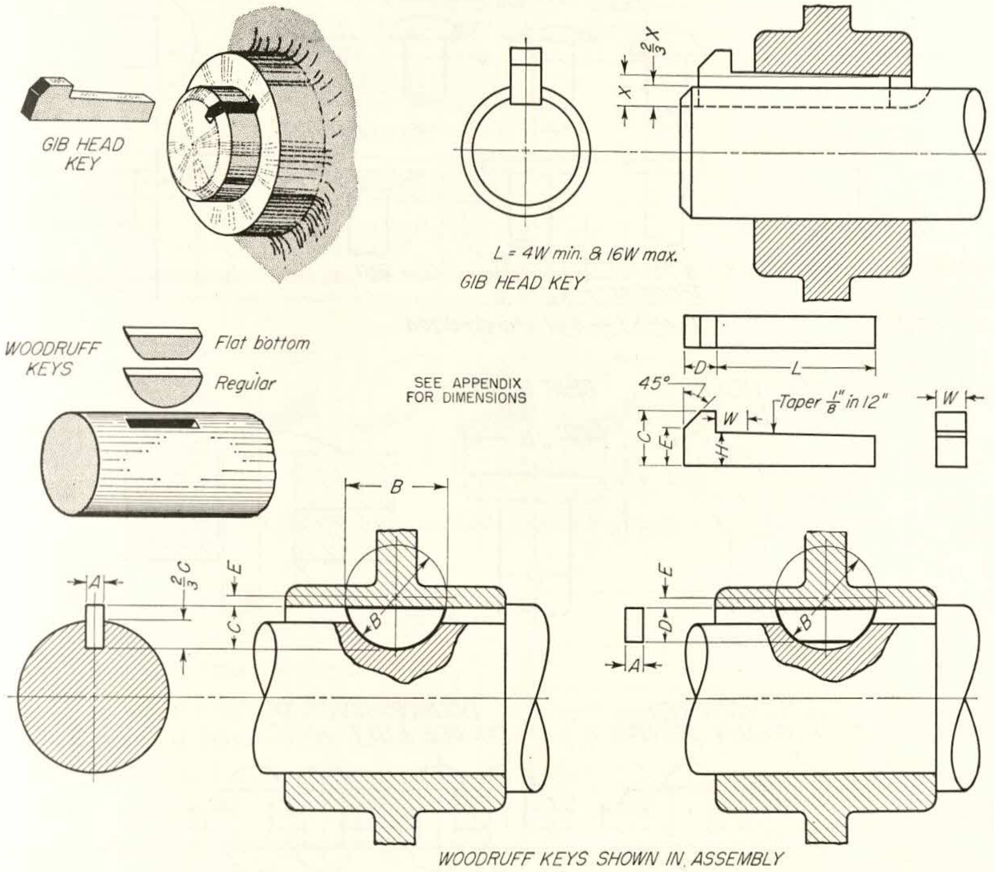


Fig. 12-34. Keys.

of rivets or a butt joint is held together by a single row of rivets on either side of the joint, the joints are said to be "single-riveted." Two rows of rivets on a lap joint or two rows of rivets on both sides of a butt joint form a double-riveted joint. Joints may be triple- or quadruple-riveted also. For large rivets, the clearance between the shank and the hole is 1/16 in. The distance from the edge of the plate to the rim of the hole should never be less than the diameter of the rivet. On large construction work, rivets that are to be driven on the job (as opposed to those driven in the shop) are called "field rivets" and are indicated as black circles on the drawing (see Fig. 12-36).

12-32. Welding. Welding is a method of making a permanent joint between two metal parts. It is used extensively in the fabrication of cylindrical forms, such as ducts and containers, and it is also used frequently in the manufacture of complicated parts in order to simplify casting procedures.

Practically all ferrous and nonferrous metals can be welded. Cast iron, steel and iron alloys, brass, copper, aluminum, etc., are used in the welding industry. The elimination of sand-casting patterns and savings in labor and material have made it possible to produce many machine parts, and in some cases whole units, at greatly reduced expense as compared with other methods of construction or fabrication.

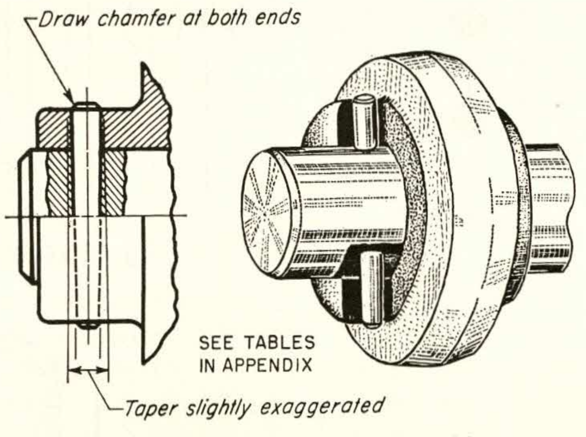


Fig. 12-35. The taper pin in assembly.

There are many different welding processes, but the ones most often used are forging, gas welding, and electric welding. In forging welds, the parts are

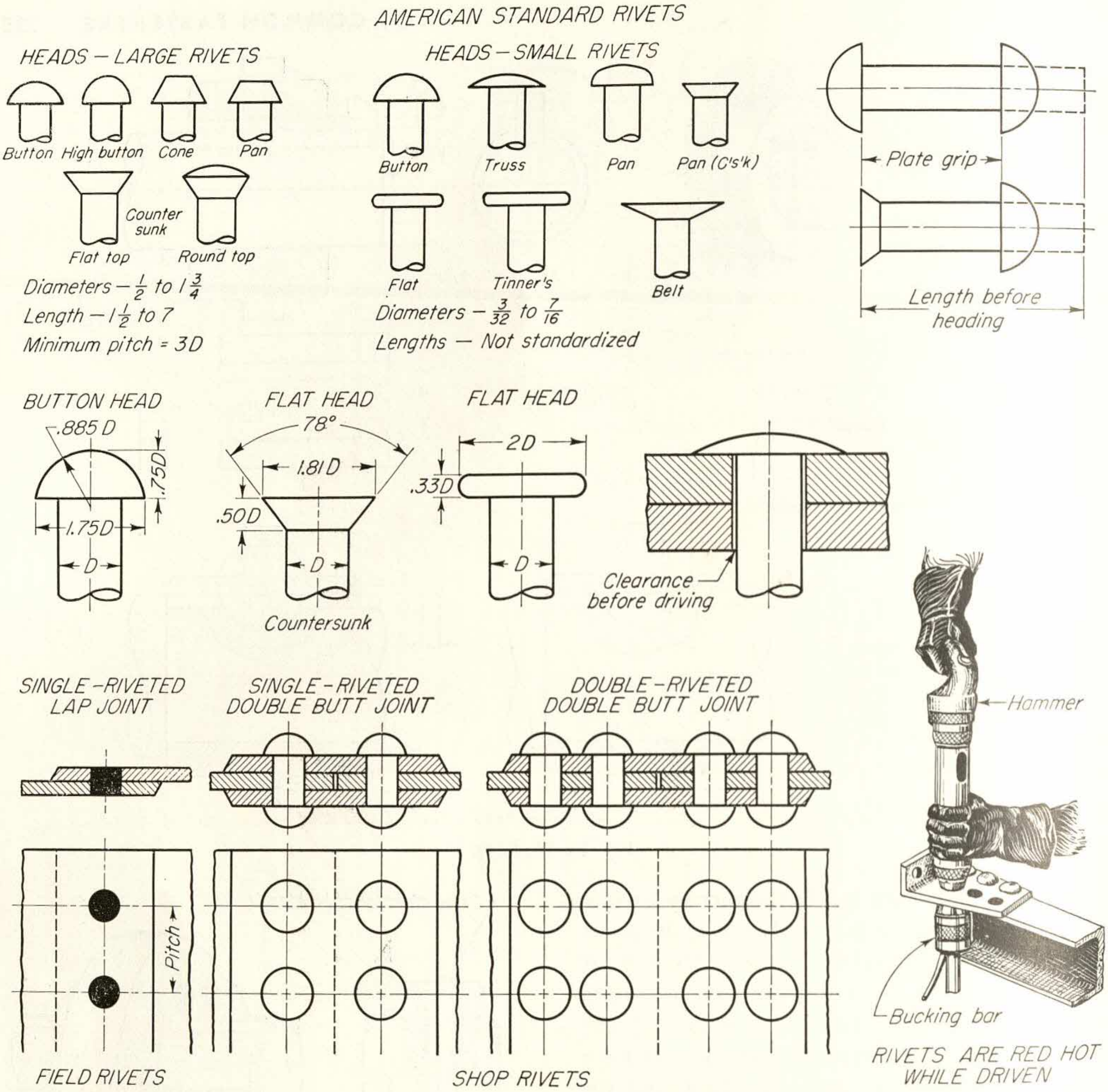


Fig. 12-36. Rivets and riveted joints.

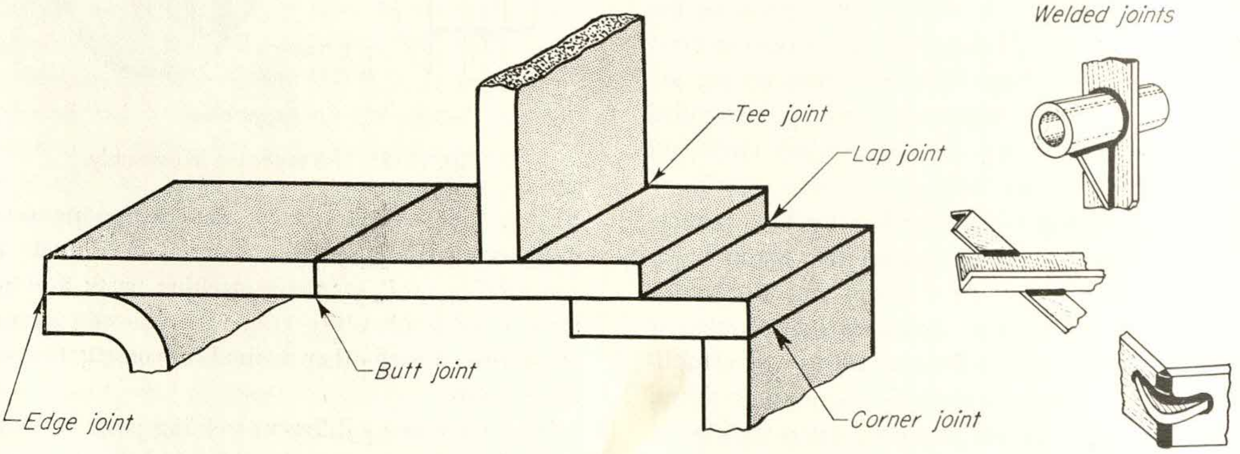


Fig. 12-37. Types of welded joints.

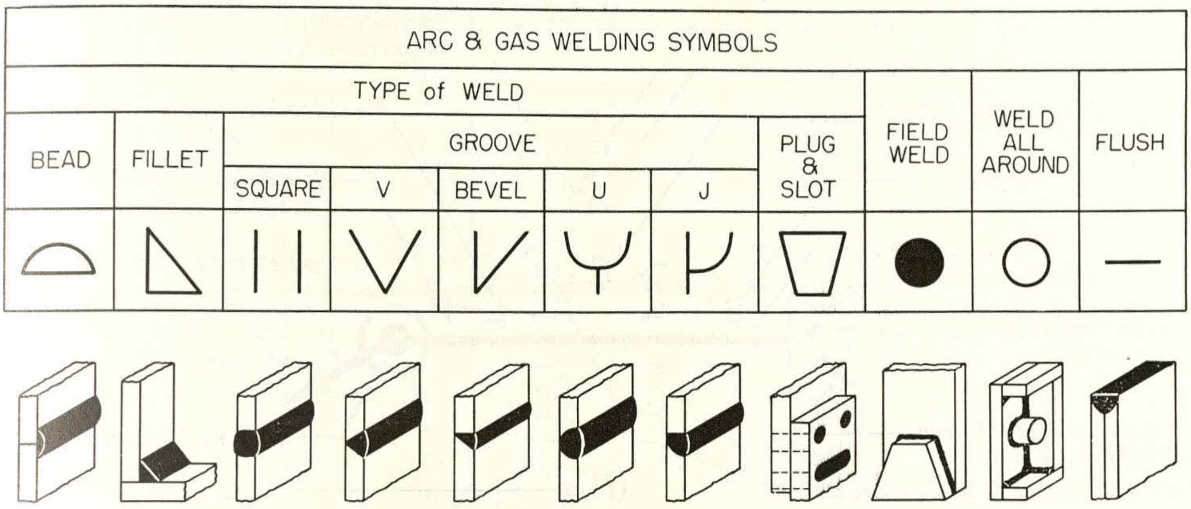


Fig. 12-38. Welding symbols and their graphic meanings.

heated until the metal is in a plastic state, and they are then joined by pressure or heavy blows from a hammer. When preparing joints for pressure welding, the metal is high, or crowned, near the center of the weld so that in the hammering procedure the joining of the metal will occur at that point and work outward toward the extremities. To avoid burning the metal and to assure a clean weld, a flux of fine sand or borax is commonly used.

Gas welding is a method whereby a gas flame is used to heat the pieces to the fusion point. The parts form a weld without the use of pressure. A flux and a filler material are often employed in the process.

Electric welding includes the two processes known as resistance welding and arc welding. Spot welding, seam welding, projection welding, and flash welding are forms of resistance welding. In electric welding, the electric current is passed through the metals to be joined. Their resistance builds enough heat within them so that when pressure is applied to the plates the fusion, or welding, takes place. In the arc-welding process, fusion is brought about without the use of pressure. However, the heating electrode used not only serves to bring the plates to a fusion heat but also supplies a filler material if the base metal is not of a sufficient quantity to ensure a safe weld.

12-33. Types of welded joints. Figure 12-37 illustrates the five types of welded joints: the *butt joint,* the *lap joint,* the *tee joint,* the *corner joint,* and the *edge joint.*

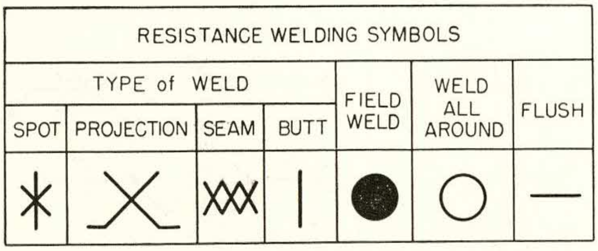


Fig. 12-39. Resistance-welding symbols.

12-34. Types of welds. The basic types of welds used to join together metal pieces are called *bead, fillet, groove,* and *plug and slot* welds (Fig. 12-38) and *spot, projection, seam,* and *butt* welds (Fig. 12-39). The groove welds are further classified as square, V, bevel, U, or J welds, where the shape of the symbol indicates the shape of the weld or the shape of the preparation needed on the pieces forming the joint.

12-35. Welding symbols. The American Standard symbol for indicating welds on drawings is shown in Fig. 12-40. The complete symbol consists of an arrowhead and leader joined to a reference line, on one or both sides of which are placed a basic symbol or symbols with figures that refer to the type of weld and its size. The tail is added to the reference line only when it is necessary to specify the type of filler material to be used, and basic symbols, letters, or figures not required in specifying a particular weld are also omitted from the complete symbol. By combining the basic symbols, any desired compound welding symbols can be constructed to indicate complicated welded

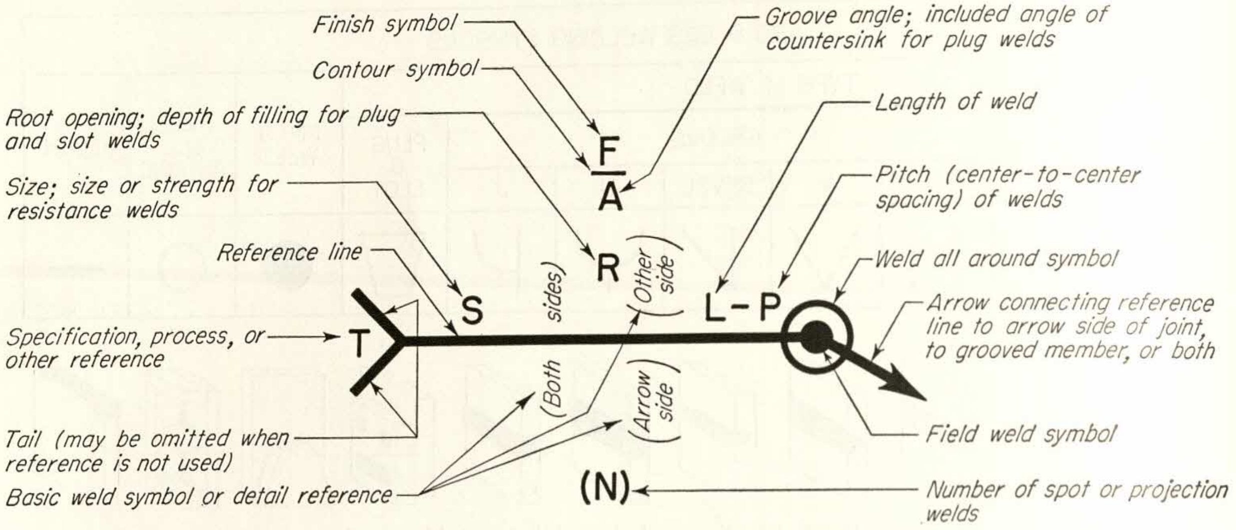

Finish symbol
Contour symbol
Root opening; depth of filling for plug and slot welds
Size; size or strength for resistance welds
Reference line
Specification, process, or other reference
Tail (may be omitted when reference is not used)
Basic weld symbol or detail reference
Groove angle; included angle of countersink for plug welds
Length of weld
Pitch (center-to-center spacing) of welds
Weld all around symbol
Arrow connecting reference line to arrow side of joint, to grooved member, or both
Field weld symbol
Number of spot or projection welds
F
A
R
S
T
L - P
(N)
(Both sides)
(Other side)
(Arrow side)

Fig. 12-40. Standard location of elements of a welding symbol. (*From ASA Z32.2.1—1949.*)

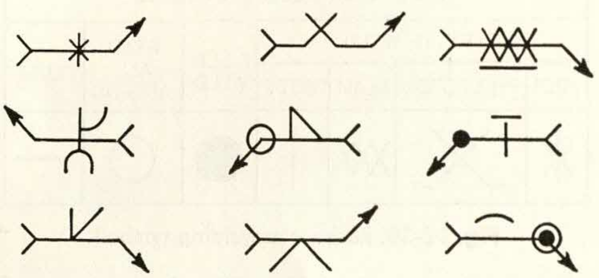
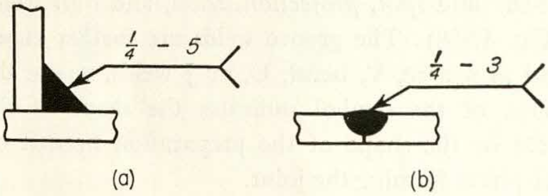


Fig. 12-41*a*. Position of basic symbols for various types of welds.



(a) (b)

Fig. 12-41*b*. Symbol used when only one or two welds appear on drawing sheet.

joints consisting of a number of different basic welds (Fig. 12-41*a*). The side of a welded joint to which the arrow points is called the "arrow side" (formerly it was called the "near side"), and the opposite side is called the "other side" (formerly termed the "far side"). If both members are to be grooved, the arrow touches the corner formed by the two plates. When only one member is to be grooved, the arrow touches that member alone just beyond the intersection. The symbol indicating the type of weld (Figs. 12-38 and 12-39) is always placed at the middle and above or below the reference line, with the perpendicular leg of the symbol (if any) to the left. The size of the weld (length of the side of the weld) is given at the left of the symbol indicating the type of weld; the length of the weld is given at the right. The symbol and size and length specifications for the arrow-side weld are placed below the reference line; the

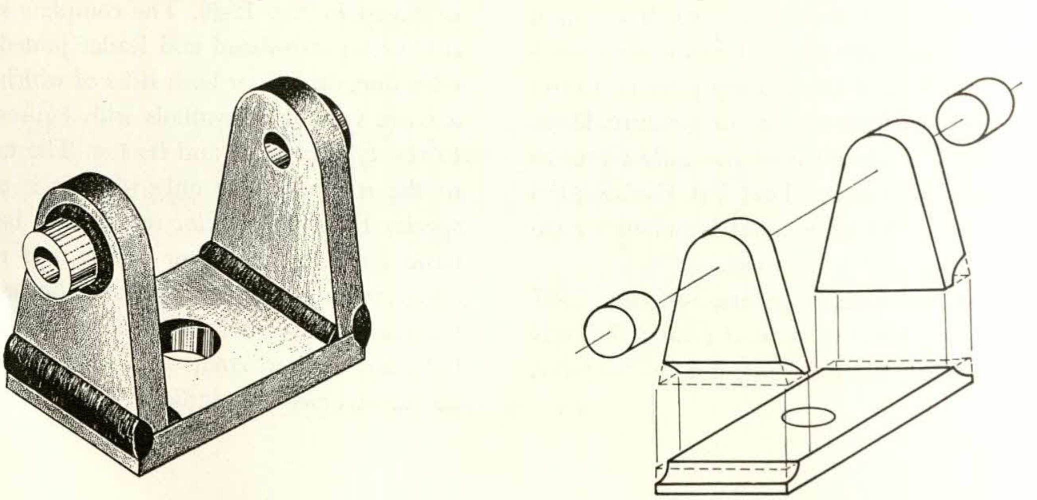


Fig. 12-42. A welded coaster frame.

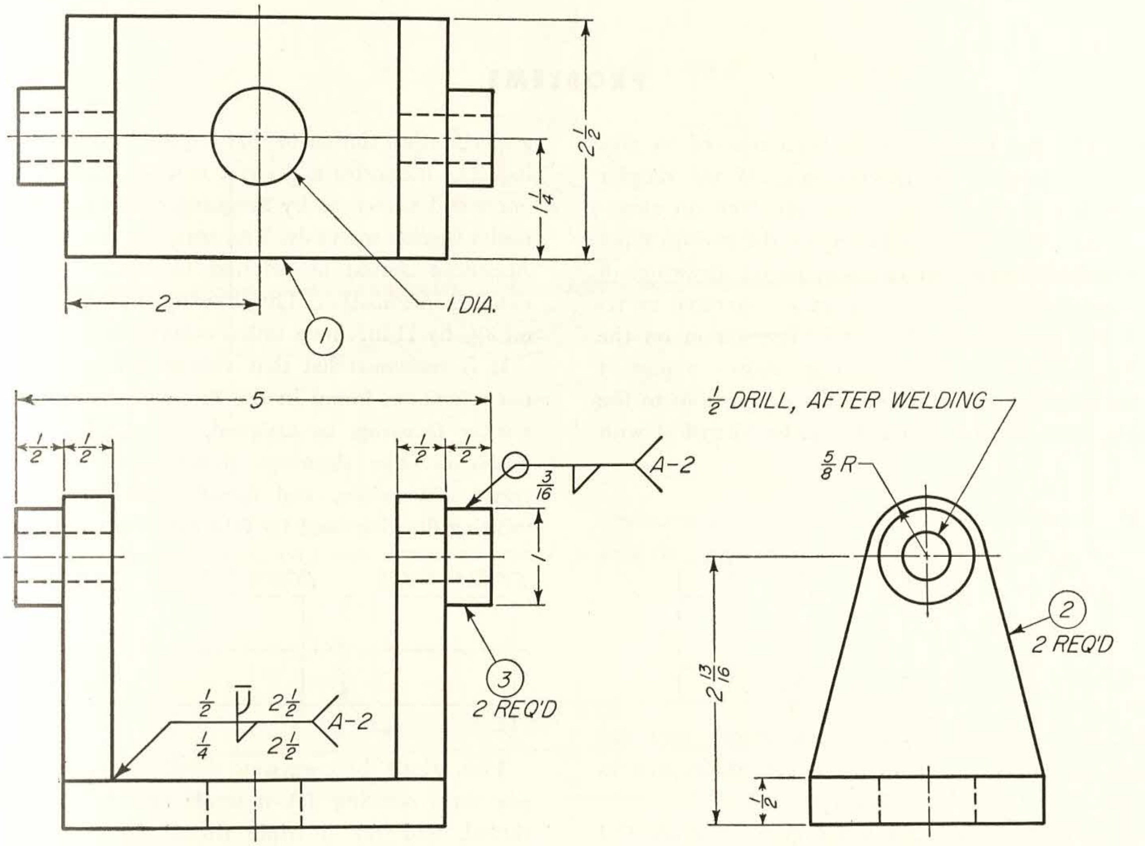


Fig. 12-43. A shop welding drawing (orthographics of coaster frame shown in Fig. 12-42).

symbol and specifications for the other-side weld are placed above the reference line. For objects that are to be manufactured or fabricated principally by welding procedures, the draftsman should represent the different welds by using the complete welding symbol with all the required specifications as recommended and illustrated in Fig. 12-40. When only one or two welding operations need be shown on the drawing sheet, it is permissible to represent the accurate cross-sectional shape and the size and length of the weld, while omitting the basic weld symbol on the reference line. See Fig. 12-41*b*: (*a*) is a ¼-in. fillet weld 5 in. in length, and (*b*) is a ¼-in. U weld 3 in. long.

The ASA has published a complete treatise on welding symbols entitled American Standard Graphical Symbols for Welding (ASA Z32.2.1—1949), which should be in the hands of all draftsmen concerned with the preparation of welding drawings. The material in this Standard was originally prepared by the American Welding Society.

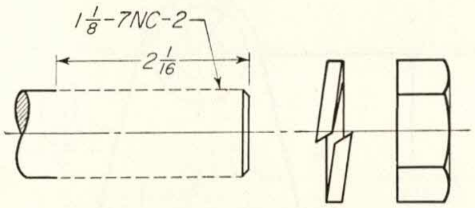
12-36. A welding drawing. Figure 12-42 shows the pictorial of a coaster frame made of welded pieces that have been cut from bar and plate-metal stock readily available in the ordinary machine shop. At the right, the single pieces have been shown before welding. Note that preparation of a piece to be welded is always required for groove welds, while fillet welds generally need no preparation other than cleaning of the surfaces.

Figure 12-43 shows a welding working drawing made for the shop. This drawing is similar to one that might be prepared for a casting of the bracket, with the exception that the pieces are numbered and symbols completely describing the welding procedure are employed. All fillets and rounds are eliminated. Note in particular that only one symbol and specification is used to identify the two identical welds joining the sides to the base, as is the case for the welds joining the bar pieces to the sides. In all welding representations, the line between the joints at the point of welding is always shown. All other necessary dimensions, notes, and information relating to fabrication, assembly, or finish are also included on the drawing or in the title block.

PROBLEMS

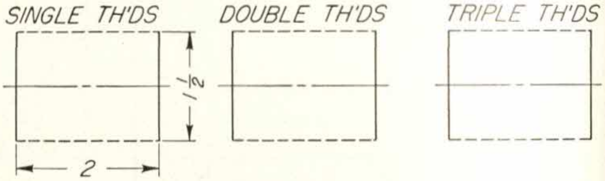
The following problems have been selected to give the student practice in drawing some of the simpler fasteners before proceeding to the problems on assembly drawing, where a great variety of the various types of common fasteners will be encountered. Drawings of dimensioned objects may be shown in increased or reduced scale to allow a pleasing representation on the drawing sheet. If no dimensions are shown, a pair of dividers may be used to transfer the proportions to the drawing sheet. Each fastener should be identified with a specification similar to that required on a detail drawing. The instructor may cover most of the common fasteners and save time by assigning only Prob. 12-26, the pulley-bracket assembly. The text and the tables in the Appendix should be referred to where necessary for detailed information. The drawings should be prepared on 8½- by 11-in. sheets unless otherwise noted.

It is recommended that various individual parts of the assemblies found in the Problems of Chap. 13, Assembly Drawing, be assigned, if suitable, as fastener problems. The drawings should show the required views, dimensions, and specifications necessary in a working drawing used for fabrication of the part.

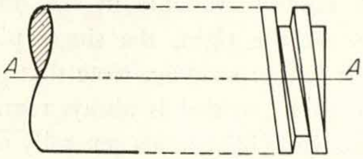


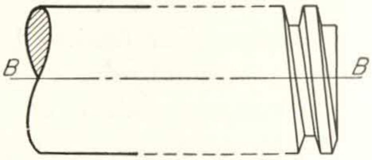
12-1. Draw detailed threads, lock washer, and hex nut for the thread shown in the figure. Show parts in assembly in the side view. (Time. 2½ hr.)

12-2. Redraw the screw and nut given in Prob. 12-1 with left-hand threads. Show the proper specifications on your drawing sheet. (Time. 2½ hr.)

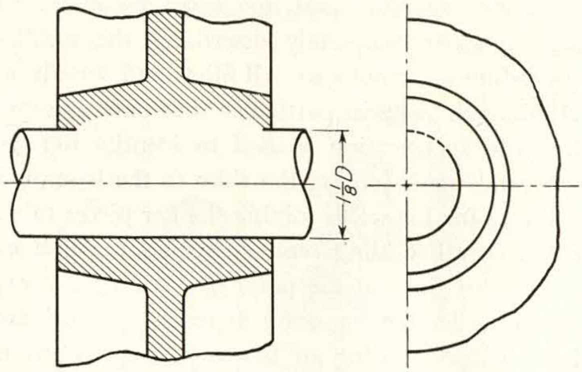


12-3. Make three separate detailed representations on one sheet showing (*a*) a single thread, (*b*) a double thread, and (*c*) a triple thread for standard screw threads on a 1½-in.-diameter shaft 2 in. long. (Time. 2 hr.)

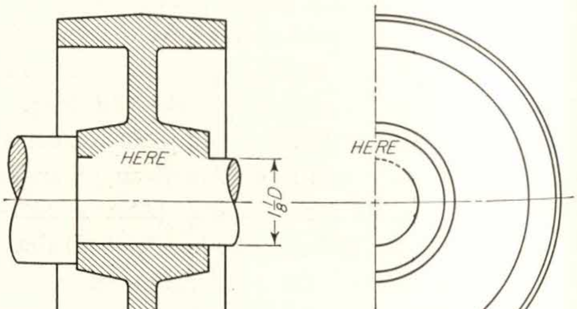




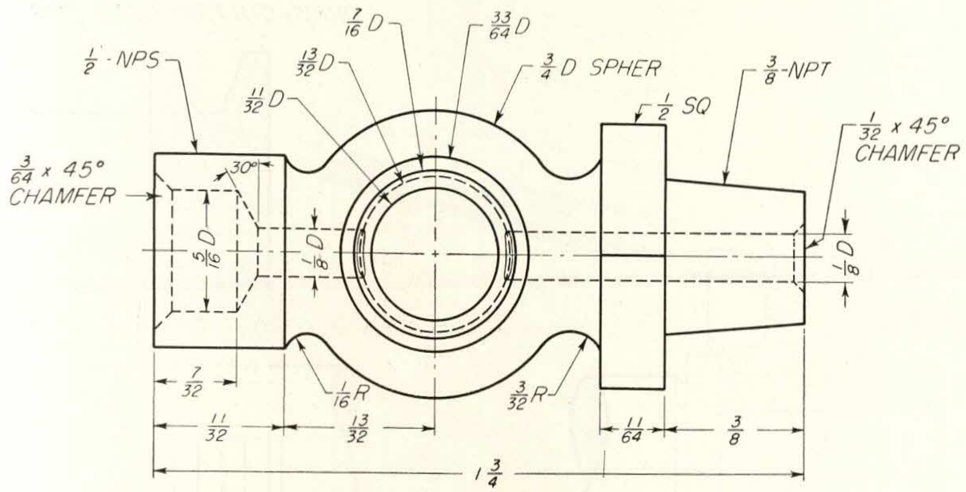
12-4. On center line *AA*, construct a detailed representation of a section of square threads 1¾ in. in diameter and 3 in. long. On *BB*, show a detailed representation of Acme threads of the same length and diameter, using four threads to the inch in each case. (Time. 2 hr.)



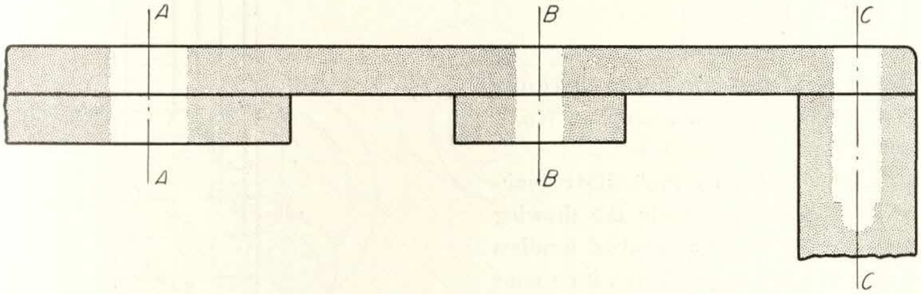
12-5. Scale the two views with dividers to twice the size shown. Draw in its proper position a square key with the dimensions ¼ × ¼ × 2. Be sure to represent the slot properly in both hub and shaft. (Time. 2 hr.)



12-6. Scale off the two views with dividers to the shaft size shown. Draw a No. 404 flat Woodruff key in the key seat. (Time. 2 hr.)

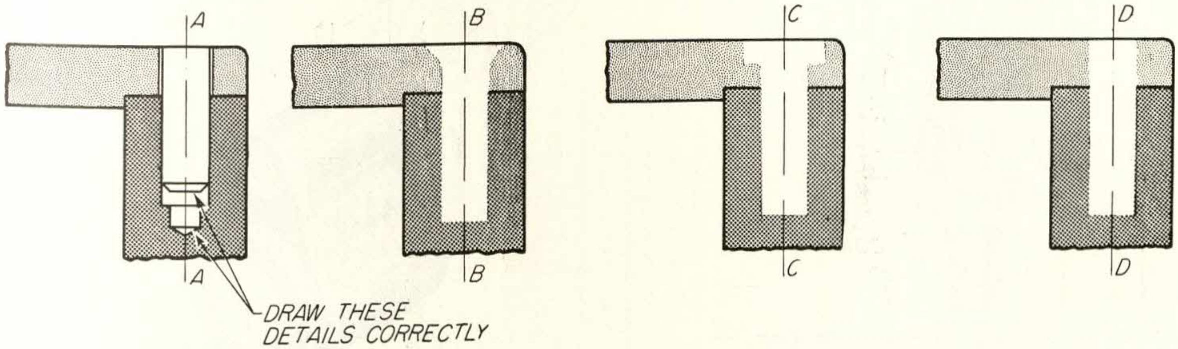


12-7. Make a one-view drawing (four times actual size) of the valve body. At each end show schematic representations of the required pipe threads. Do not dimension the drawing. (Time. 2 hr.)

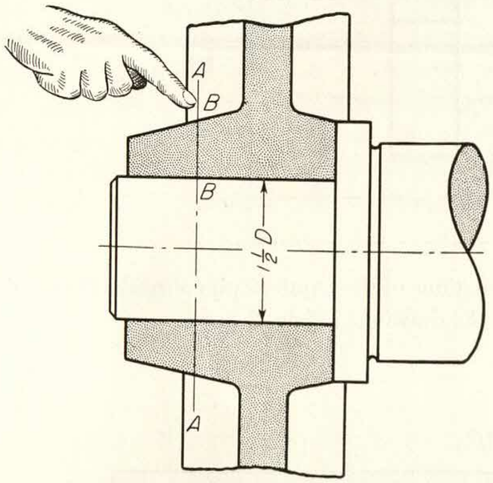


12-8. Reproduce a figure similar to the one shown in the illustration, and draw an ordinary top and a section front view of the following fasteners: At *AA,* show a square-head bolt ⅞ in. in diameter and 1⅝ in. long with a square nut. At *BB,* show a semifinished hex-head bolt ½ in. in diameter and 1¾ in. long with a standard plain washer and a standard semifinished hex-head nut. At *CC,* show a stud bolt ½ in. in diameter and 2⅛ in. long, thread at nut end 1 in., at the stud end ⅞ in., with a standard lock washer and a hex nut. The threads for all the bolts should be indicated with unified specifications and shown in schematic form. (Time. 3 hr.)

12-9. With the specifications given in Prob. 12-6, show the threads in the *simplified* form. (Time. 3 hr.)

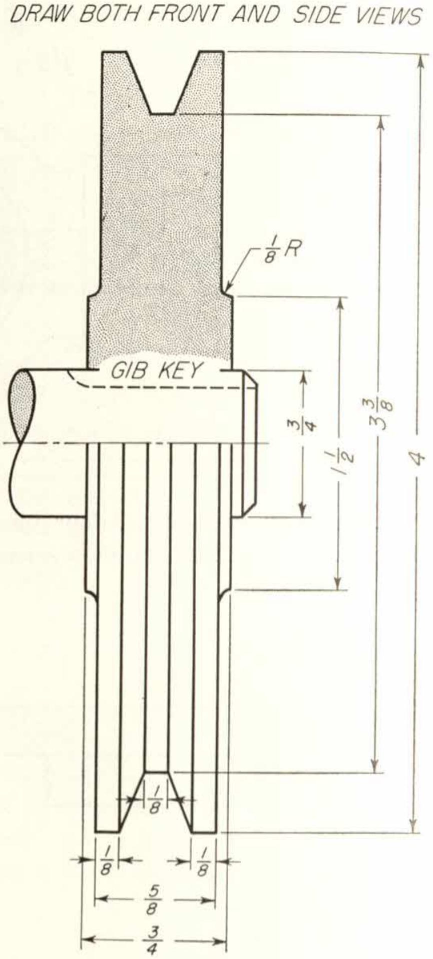


12-10. Reproduce the joints about twice the size shown on an 11- by 17-in. sheet. Draw an ordinary top view and a front view in section. At *AA,* show a hex-head cap screw with the following specifications: ½ × 1½-13 UNC-2A. At *BB,* show a flat-head cap screw with the following specifications: 7/16 × 1⅜-14 UNC-2A. At *CC,* show a fillister-head machine screw with the following specifications: ⅜ ×1¼-16 UNC-2A. At *DD,* show a round-head cap screw with the following specifications: ⅝ × 1¾-11 UNC-2A. (Time. 4 hr.)

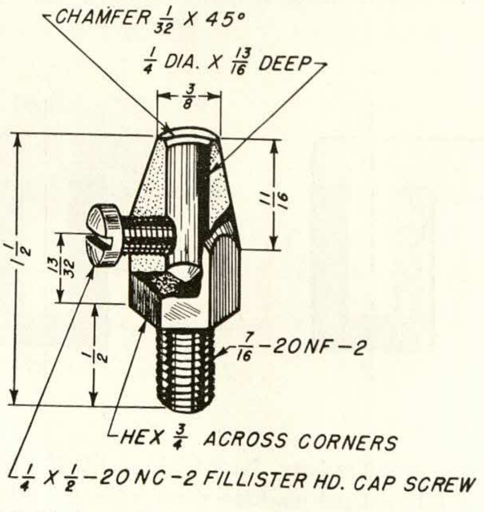


12-11. Scale off the view with dividers to twice the size shown. On center line *AA*, draw a standard No. 6 taper pin. (Time. 1½ hr.)

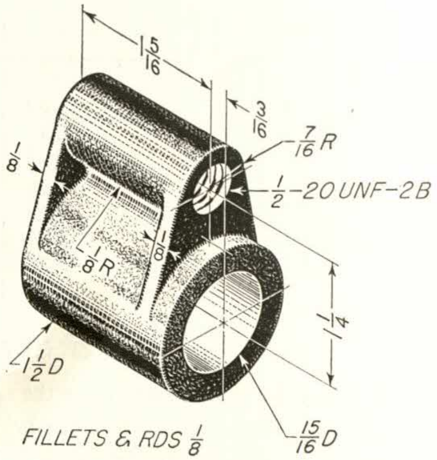
12-12. Reproduce the drawing for Prob. 12-11, omitting the line *AA*. Use dividers to scale the drawing twice the size shown. At *BB*, draw a standard headless setscrew ¼ in. in diameter and $\frac{9}{16}$ in. long with a cone point. (Time. 1½ hr.)



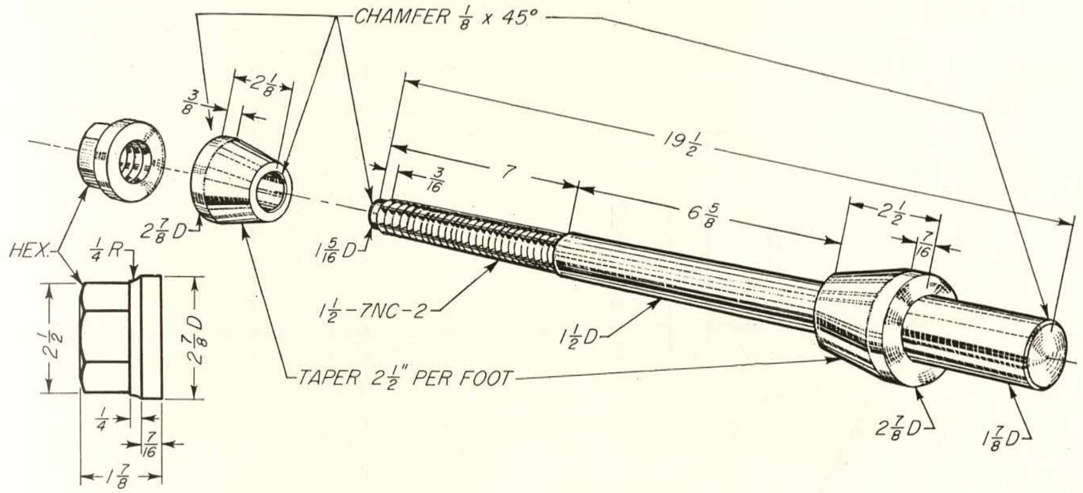
12-13. Redraw the given view, and show the circular view of the pulley. Draw a standard square-type gib-head key with dimensions $\frac{3}{16}$ in. square by $1\frac{1}{16}$ in. long. Dimension the drawing completely. (Time. 4½ hr.)


CHAMFER $\frac{1}{32}$ X 45°
$\frac{1}{4}$ DIA. X $\frac{13}{16}$ DEEP
$\frac{3}{8}$
$\frac{11}{16}$
$1\frac{1}{2}$
$\frac{13}{32}$
$\frac{1}{2}$
$\frac{7}{16}$-20NF-2
HEX $\frac{3}{4}$ ACROSS CORNERS
$\frac{1}{4}$ X $\frac{1}{2}$-20NC-2 FILLISTER HD. CAP SCREW

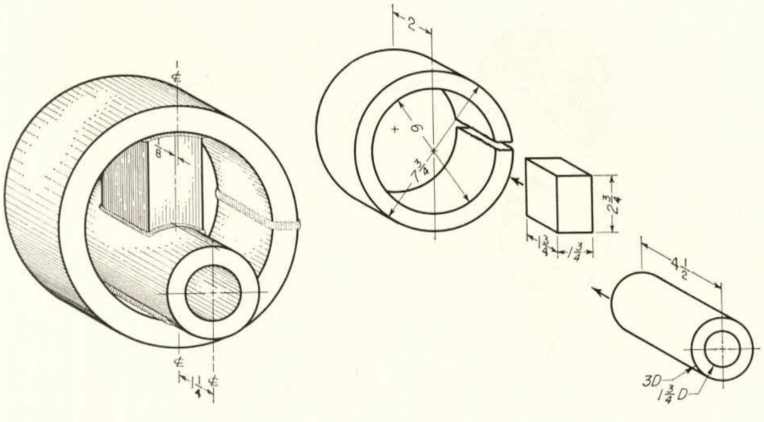
12-14. Redraw the cap screw and the body of the drill chuck as separate details. Dimension the drawing completely. (Time. 4 hr.)



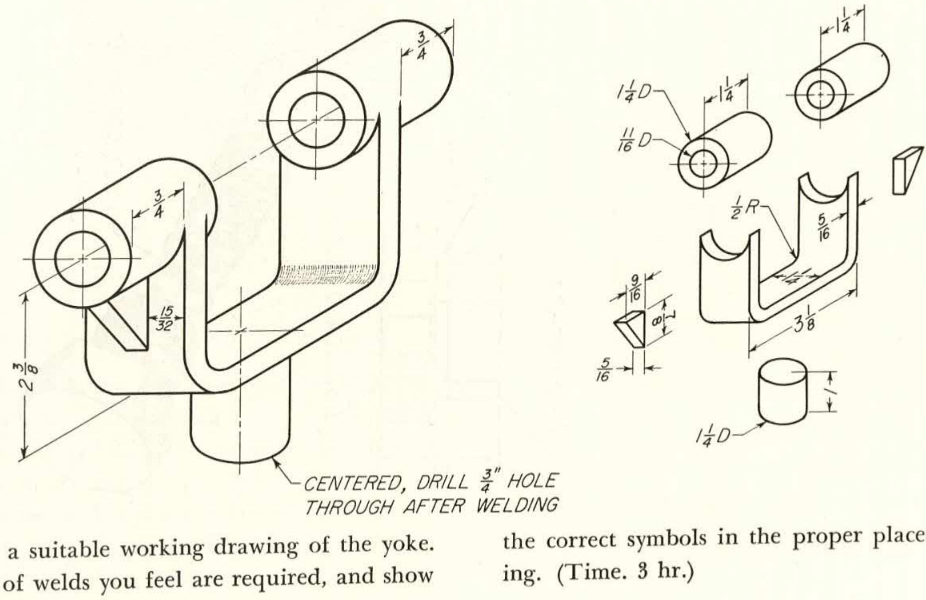
12-15. Make a completely dimensioned detail drawing of the shaft support.



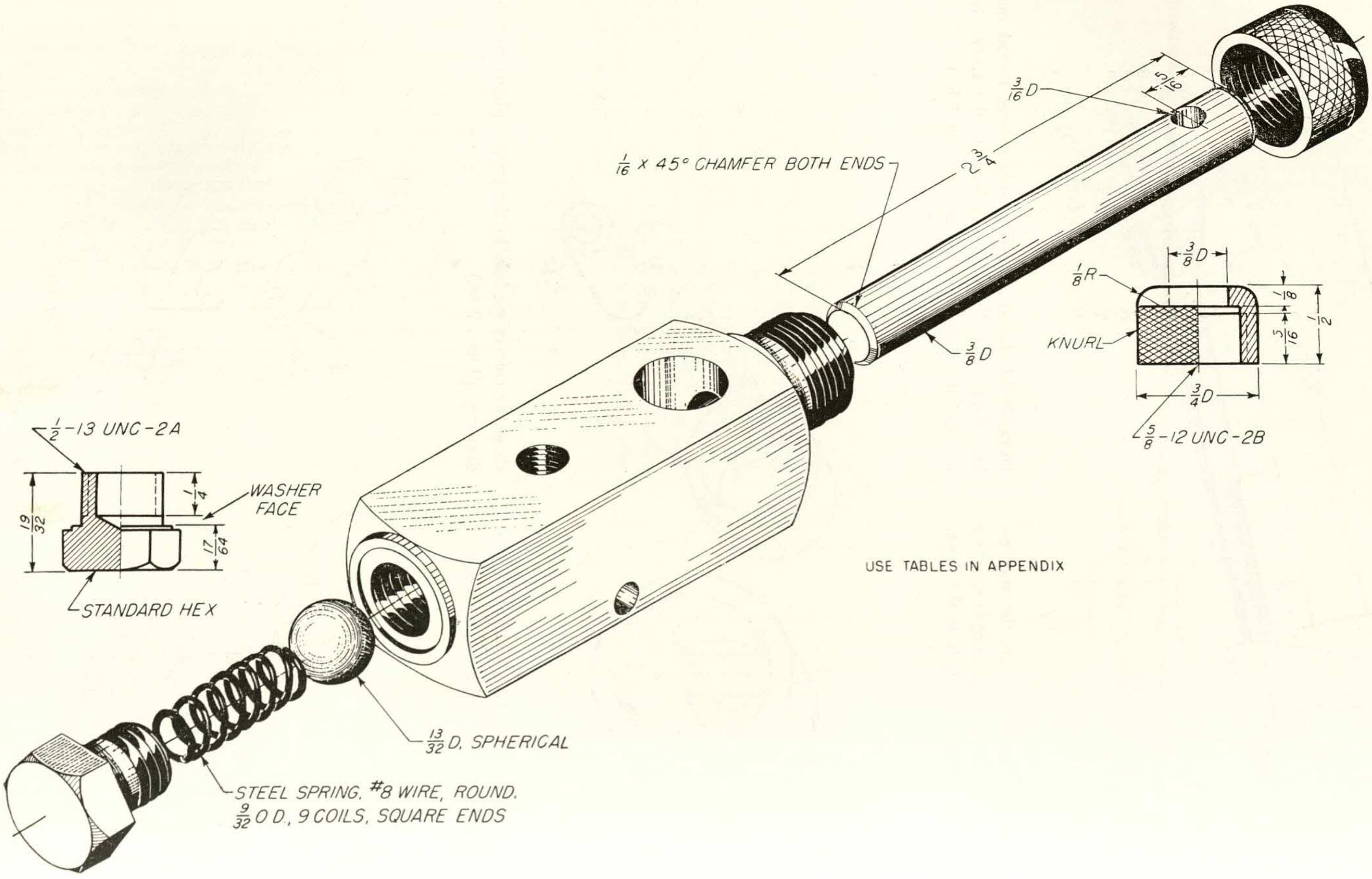
12-16. On an 11- by 17-in. sheet, draw the nut, tapered bushing, and shaft of the milling arbor as separate details. Break the shaft to permit placing it on the sheet. Draw detail threads, showing only several thread outlines and using ditto lines to indicate the others. Dimension the drawing completely. (Time. 5 hr.)



12-17. Make a suitable working drawing of the eccentric. Select the type of welds you feel are required, and show the correct symbols in the proper places on your drawing. (Time. 2 hr.)



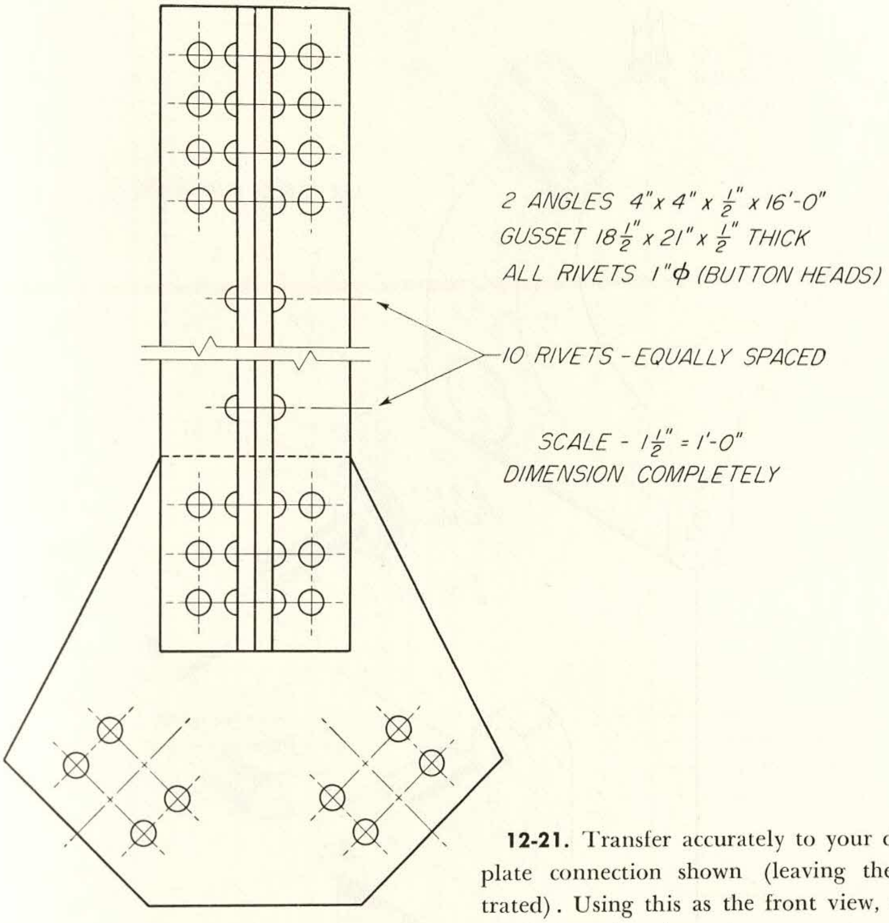
12-18. Make a suitable working drawing of the yoke. Select the type of welds you feel are required, and show the correct symbols in the proper places on your drawing. (Time. 3 hr.)



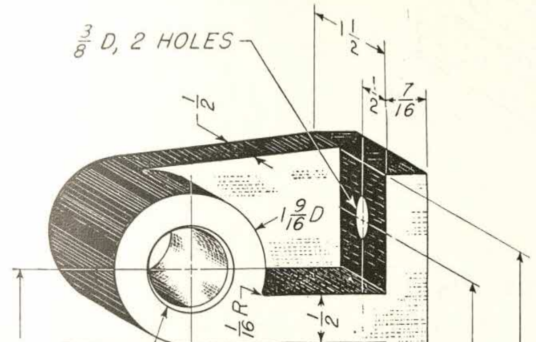
USE TABLES IN APPENDIX

12-19. On a single 8½- by 11-in. sheet, show the necessary views of the plunger shaft, the steel spring, and the steel ball bearing of the illustrated grease-pump unit. Select a suitable scale, and show the correct dimensions and specifications for each part.

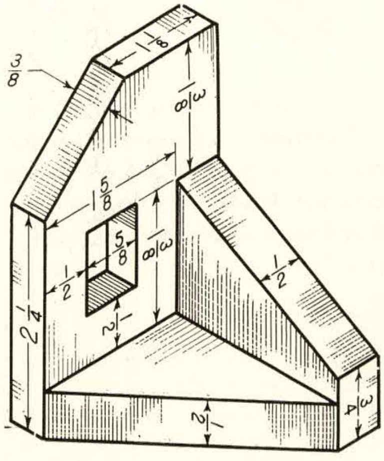
12-20. On a single 8½- by 11-in. sheet, show the necessary views of the steel spring retaining bolt and the steel packing nut of the grease-pump unit. Select a suitable scale, and show the correct dimensions and specifications for each part.


2 ANGLES 4"x 4" x 1/2" x 16'-0"
GUSSET 18 1/2" x 21" x 1/2" THICK
ALL RIVETS 1"ϕ (BUTTON HEADS)
10 RIVETS - EQUALLY SPACED
SCALE - 1 1/2" = 1'-0"
DIMENSION COMPLETELY

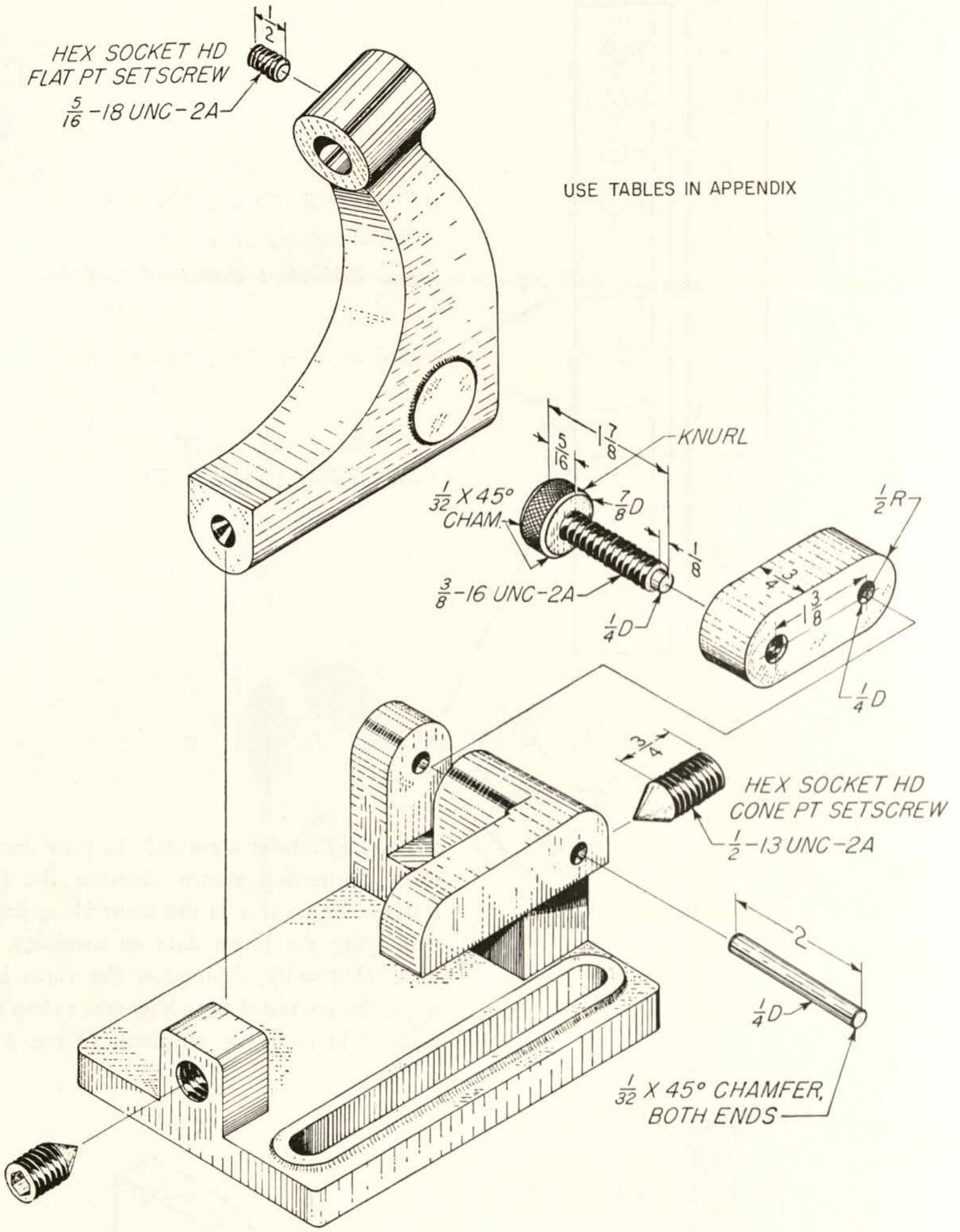
12-21. Transfer accurately to your drawing sheet the plate connection shown (leaving the break as illustrated). Using this as the front view, draw a side view employing the given data as necessary. At the given scale (1½" = 1'), dimension the views completely. Indicate by an added note how many shop rivets and how many field rivets are required. (Time. 4 hr.)



12-22. The shaft support illustrated can be produced as a welded form by bringing together four separate parts that include a cylindrical piece. Show the support as a welding drawing, indicating clearly each part and the proper location and representation of the symbols for the welds you have selected, with all dimensions and notes required for complete fabrication.



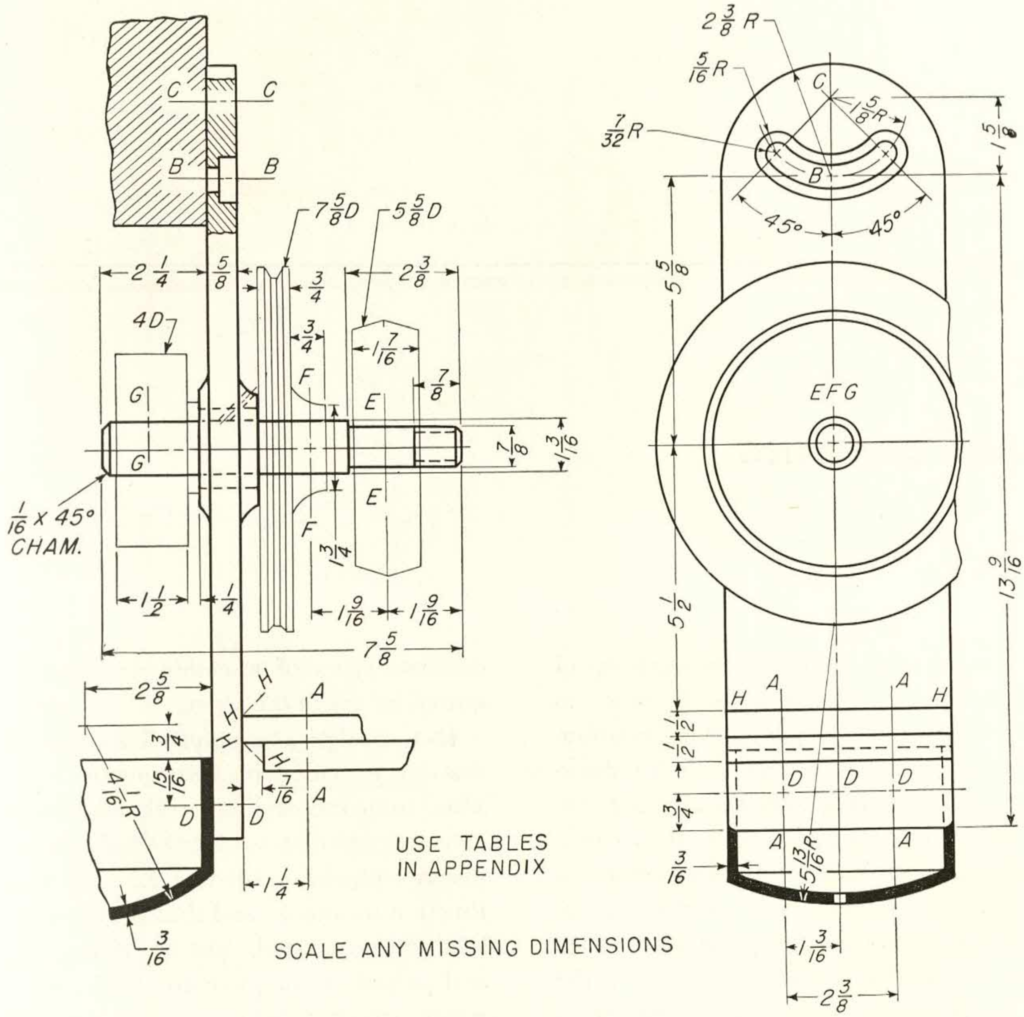
12-23. The corner block illustrated is made up of three separate pieces. Draw the object at a suitable scale as a welding drawing, correctly dimensioned, with the proper symbols for the welds you have selected to hold the pieces together.



USE TABLES IN APPENDIX

12-24. On a single 8½- by 11-in. sheet, show the necessary views of the tool setscrew, the (dimensioned) support setscrew, and the lever pin of the special toolholder. Select a suitable scale, and show the correct dimensions and specifications for each part.

12-25. On a single 8½- by 11-in. sheet, show the necessary views of the support lever and the knurled lever screw of the special toolholder. Select a suitable scale, and show the correct dimensions and specifications for each part.



USE TABLES IN APPENDIX

SCALE ANY MISSING DIMENSIONS

12-26. The assembly has been designed to fit an 11- by 17-in. sheet with ample room for a title block and bill of materials at the right of the two views when drawn to a scale of half size. However, the instructor may assign the problem, omitting the representation of the pulleys if he desires, or he may assign only such parts as will fit a selected sheet size. Both front and side views should be drawn.

At *AA,* draw a ¾ × 2-10 NC-2 square-head bolt with a hex nut and standard lock washer, two required.

At *BB,* ⅜ × 1-16 NC-2 fillister-head cap screw.

At *CC,* ⅝ × 2¼-11 NC-2 stud bolt, 1-in. threads on both ends, with plain washer and hex nut.

At *DD,* ⅜ × 1½ button-head rivet, three required.

At *EE,* No. 304 round-bottom Woodruff key.

At *FF,* No. 4 standard taper pin.

At *GG,* flat gib-head key 1¼ in. long for a 1³⁄₁₆-in.-diameter shaft.

At *HH,* ¼-in. double fillet weld.

The threads at the right end of the shaft are ⅞ in. long and are ⅞-14 NC-2 for a standard hex nut and matching standard lock washer.

Use sectioning where the fasteners may be shown advantageously in this manner. Specify each fastener properly, but do not dimension the structural forms. (Time. 9 hr.)

Chapter 13

ASSEMBLY DRAWING

Most mechanisms and structures are made up of a various number of different parts. In order to show these parts in their proper working relationship, it is necessary to prepare an assembly drawing. The assembly drawing may show either the external features of a group of parts, or it may be a section view that shows internal as well as external features. Since the creation of a mechanism involves many steps, from the inception of the idea in the designer's mind to the final assembly of the component parts, it is obvious that a number of different types of assembly drawings may be required for use in the plant.

13-1. Design assembly. This type of assembly drawing is made with instruments, full size if possible, from the original freehand sketches and engineering calculations for the individual parts. Emphasis is placed on the way the parts go together or function in unison, and thus the drawing is usually left undimensioned. Section views, hidden lines, and partial or complete auxiliaries are used freely where necessary for clarity (see Fig. 13-1). Detail

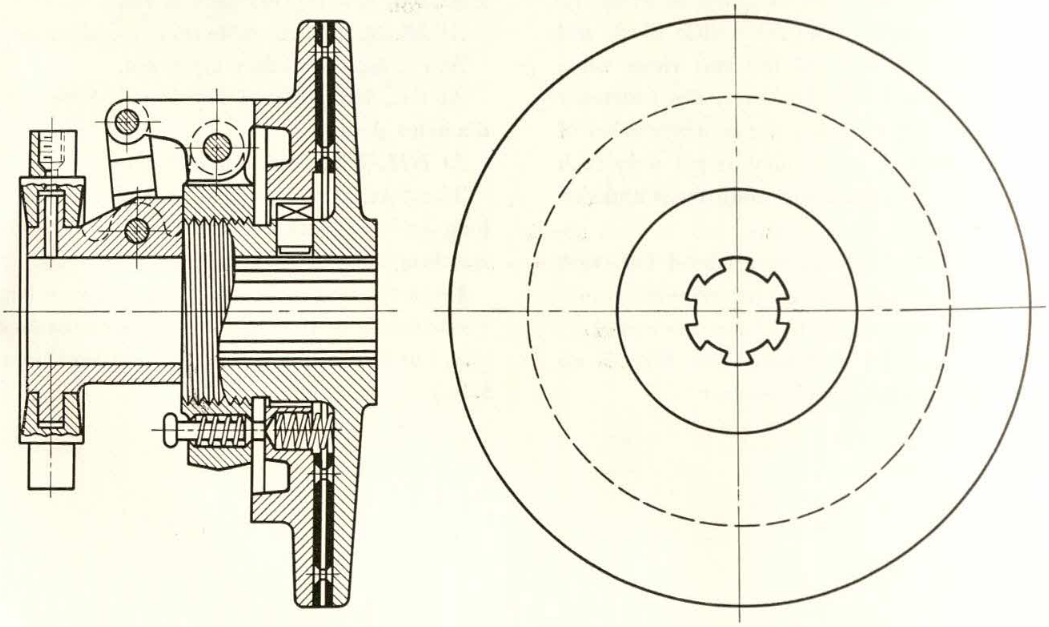


Fig. 13-1. A design assembly of a clutch unit.

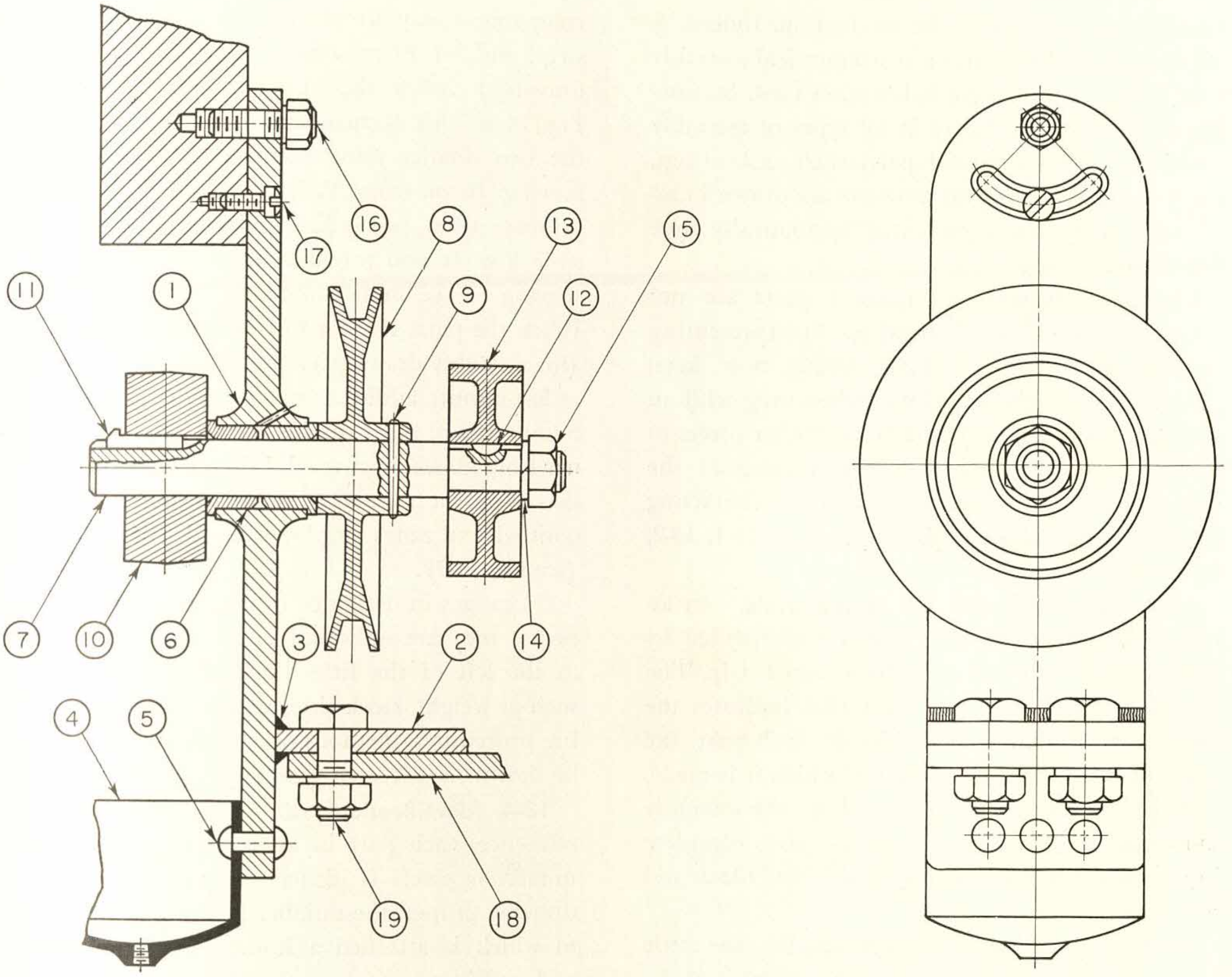


Fig. 13-2. The general assembly (pulley-bracket unit).

drawings and general assembly drawings are made from design assemblies.

13-2. General assembly. A general-assembly drawing shows the details (individual parts) of a mechanism or structure in their proper working relationship. The general assembly may be traced from the design assembly or prepared directly from the drawings of the details. If the assembly is simple, individual parts, fully dimensioned, may also be shown on the same sheet and separate detail drawings are not necessary. Usually, only two views of the assembly are shown: a main view and a view in section (see Fig. 13-2). Sometimes, however, when an assembly is not complicated, a single section view suffices.

The section view should show all significant parts and how they fit together. Adjacent parts should be sectioned in opposite directions, using the conventional section lining (see Sec. 8-9) to indicate the different materials. As explained in Chap. 8, ribs, webs, bolts, nuts, shafts, keys, pins, etc., should not be shown sectioned. Hidden lines are omitted in both views whenever feasible because they tend to overload the drawing and confuse the shopman. They may be used sparingly, however, where they aid in identifying or clarifying the position of unusual details or special parts. The individual parts appearing in a general-assembly drawing are not dimensioned, but over-all dimensions to show clearances, distances between important centers, and alternate positions of details that might change the working size of the mechanism are usually indicated.

If the unit is symmetrical, a half section can frequently be used advantageously, for it shows the external appearance as well as the internal relationship of the parts of the mechanism. Indeed, it is often possible to describe a symmetrical assembly completely with a single half-section view. Sectioning should be used freely in all types of assembly drawings. When standard parts such as bearings, cables, chains, pipes, and fasteners are drawn in assemblies, they are represented symbolically (see Fig. 13-3).

Clearances between component parts are not shown in an assembly drawing. In representing fasteners such as rivets, bolts, screws, nuts, keys, pins, etc., or bearings, springs (when snug with an internal or external fit), shafts, and other pieces in contact with other parts or the housing of the unit, a single line is used to indicate the contacting surfaces of the adjacent parts (see Figs. 13-1, 13-2, and 13-10).

13-3. Title block and bill of materials. In assembly drawings, the title box is accompanied by a bill of materials and often by a record strip. The bill of materials is a parts list that indicates the number or symbol used to identify each part, the name of the part, the material of which it is made, and the number required in making the assembly shown in the drawing. Figure 13-4 gives complete information on the drawing of the title block and bill of materials.

Most engineering drawings display the title block with its record strip (often required on detail drawing sheets) just above the lower border on the paper, as seen in Fig. 13-5. However, many companies today are placing the title block, record strip, and *bill of materials* (required for assembly drawings) below the upper border, as shown in Fig. 13-6. This arrangement permits inspection of the two smaller standard-sized sheets without removing them from their positions in the filing cabinet, thus precluding misplacement or possible loss. It also provides a suitable area for the spacing of the most commonly represented views. When the parts list (or bill of materials) is added (for assembly drawings), omissions can be rectified or last-minute additions made very readily and the numbering of parts carried out in the logical manner from above downward. When the assembly consists of only a few parts, the bill of materials can be omitted and notes employed to identify each part (see Fig. 13-7).

If changes in design or other alterations are necessary, they are indicated in a *record strip* placed to the left of the title block. Other information such as weight, stock sizes, special finishes, machining procedures, methods of assembly, etc., may also be shown in this strip (see Figs. 13-5 and 13-6).

13-4. Identification of parts. For ease of reference, each part in an assembly consisting of numerous pieces is identified by number. On the drawing proper, the number is centered in a circle, to which is attached a leader extending radially and terminating in an arrow that touches a boundary line of the part it identifies (see Fig. 13-8). The circles should be grouped about the assembly

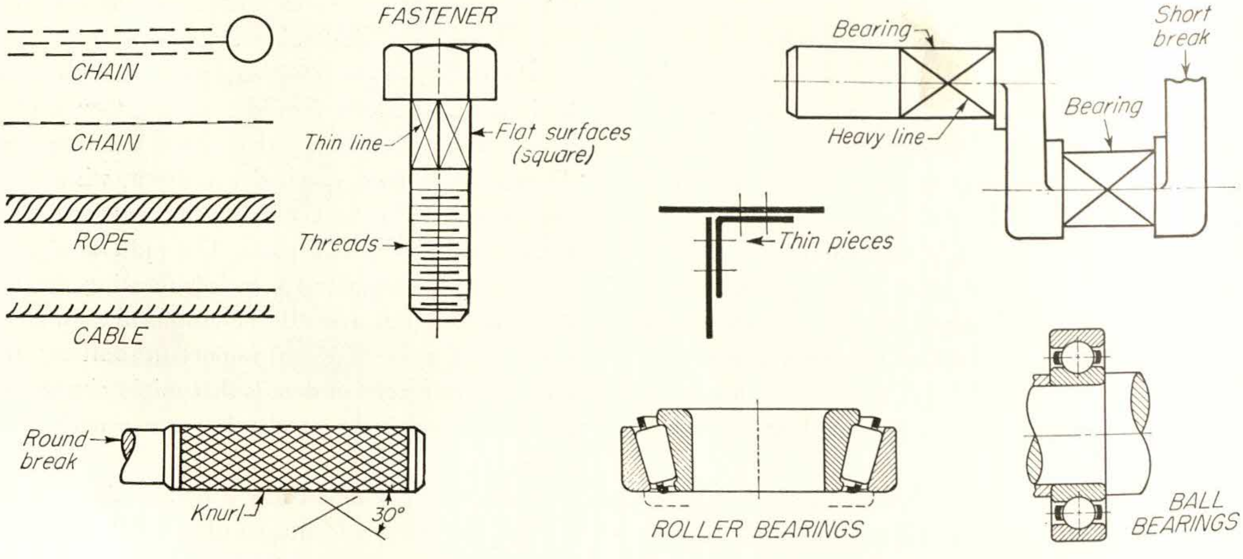
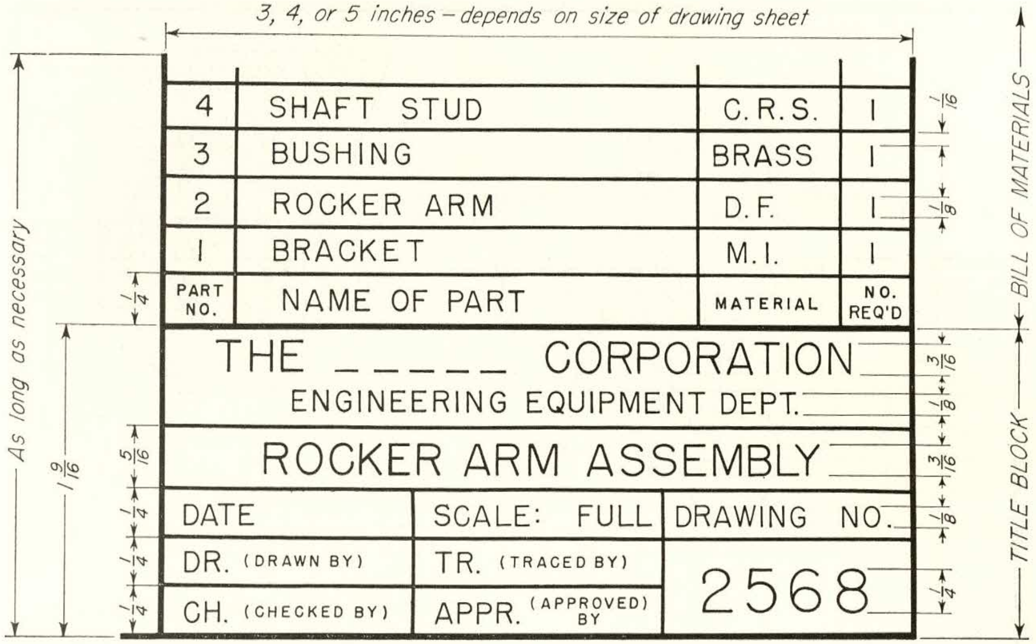


Fig. 13-3. Symbolic representations of standard parts in assembly drawings.



PART NO.	NAME OF PART	MATERIAL	NO. REQ'D
4	SHAFT STUD	C.R.S.	1
3	BUSHING	BRASS	1
2	ROCKER ARM	D.F.	1
1	BRACKET	M.I.	1

USE GUIDE LINES – SPACE WORDS EVENLY IN BLOCKS
ALWAYS USE CAPITAL LETTERS

Fig. 13-4. The title block and bill of materials, or parts list.

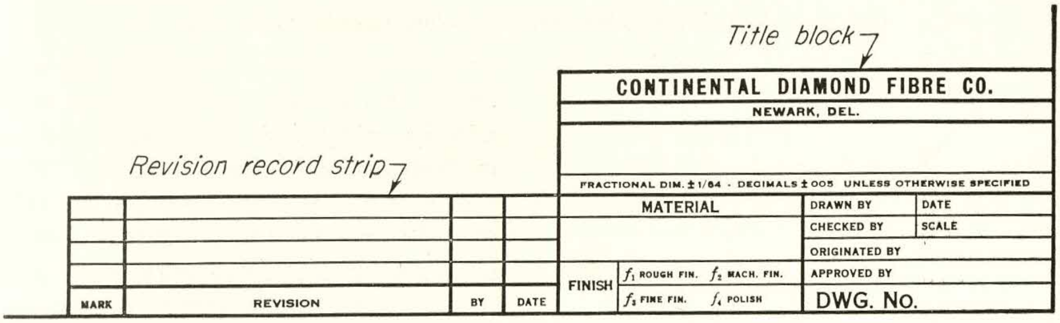


Fig. 13-5. Title block with record strip (placed at lower right on sheet).

in an orderly manner, arranged horizontally, vertically, or staggered, and should not be crowded or placed so that the leaders cross. The parts should not be numbered haphazardly, but should be identified according to a logical system. They may be numbered according to size, starting with the largest piece as number 1 and continuing progressively to the smaller ones with the higher numbers, or they may be numbered according to the material (cast iron, steel, copper, brass, aluminum, etc.) of which they are made. A better method, however, which has been widely adopted, is to number the parts according to the sequence in

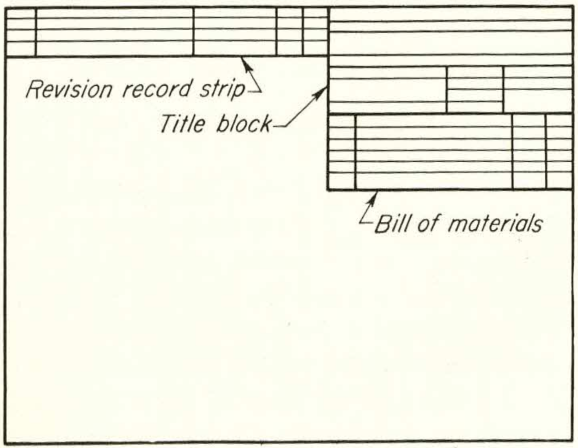


Fig. 13-6. Title block, record strip, and bill of materials (placed along upper border of sheet).

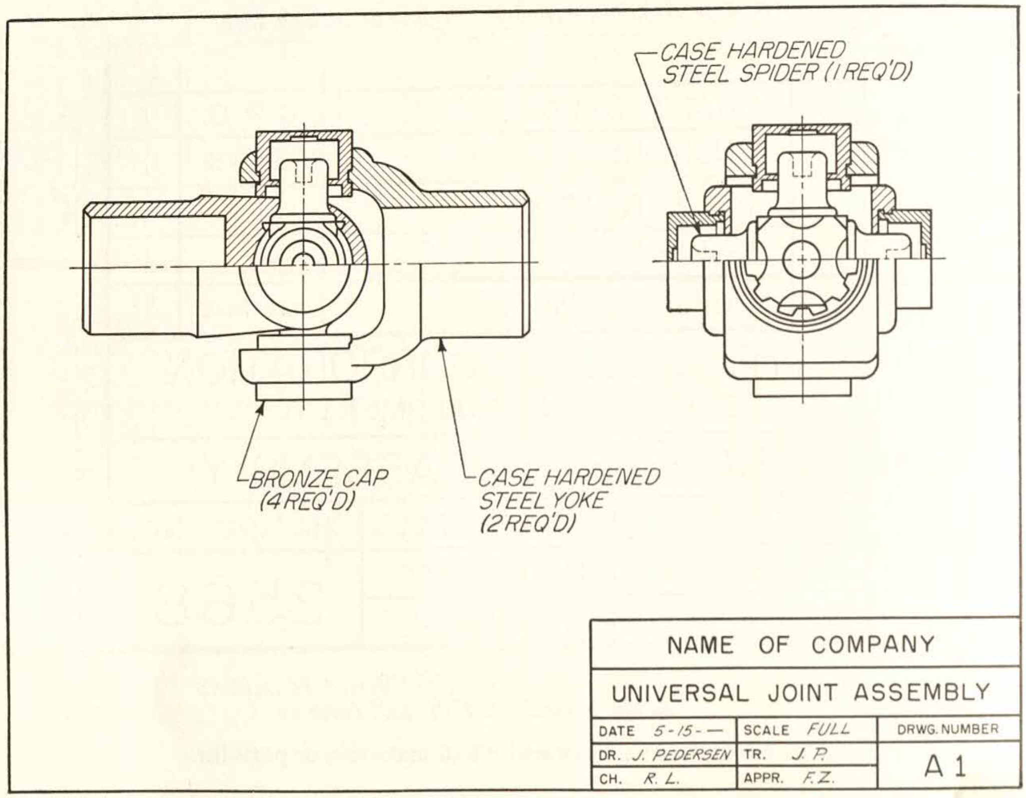


Fig. 13-7. Assembly drawing of few parts (universal-joint assembly).

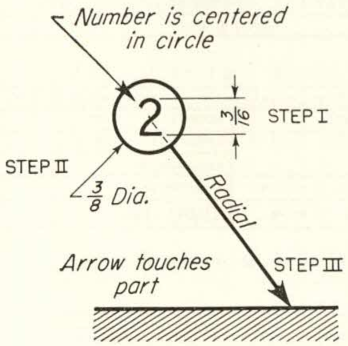


Fig. 13-8. Identification number and arrow.

which they will be handled by the worker who is to assemble them (Fig. 13-9).

13-5. Unit assembly. It is usually impractical or impossible to show on the drawing sheet a clear and useful complete assembly of a large or very complicated mechanism. To present a more comprehensive picture of the many details of, let us say, an internal-combustion engine, the draftsman must prepare a series of drawings of the smaller units that make up the entire engine. The preparation of a detailed assembly of a portion of the whole, such as the fuel pump, the distributor, the fan mechanism, or a connecting rod coupled to the piston with its wrist pin, is known as a "unit assembly," or "subassembly" (see Fig. 13-10). The unit assembly should provide, by means of notes, any information necessary for assembly to the larger mechanism, such as drilling operations, or finishing, pressing, crimping, or welding procedures required for the attachment. The individual parts themselves are not dimensioned. However, over-all dimensions that show the clearance space necessary for the unit and its dimensions for center to center, center to a finished surface, or finished surfaces to finished surfaces may be required along with the other informative notes to facilitate the assembly procedure.

13-6. Group assembly. When a number of unit assemblies are shown combined in their working relationship, the drawing is known as a "group assembly." No dimensioning is required, although the parts should be identified by complete notes or by numbers referring to a parts list.

13-7. Working-drawing assembly. If a complete mechanism consists of only a few parts or of a number of parts of simple design and construc-

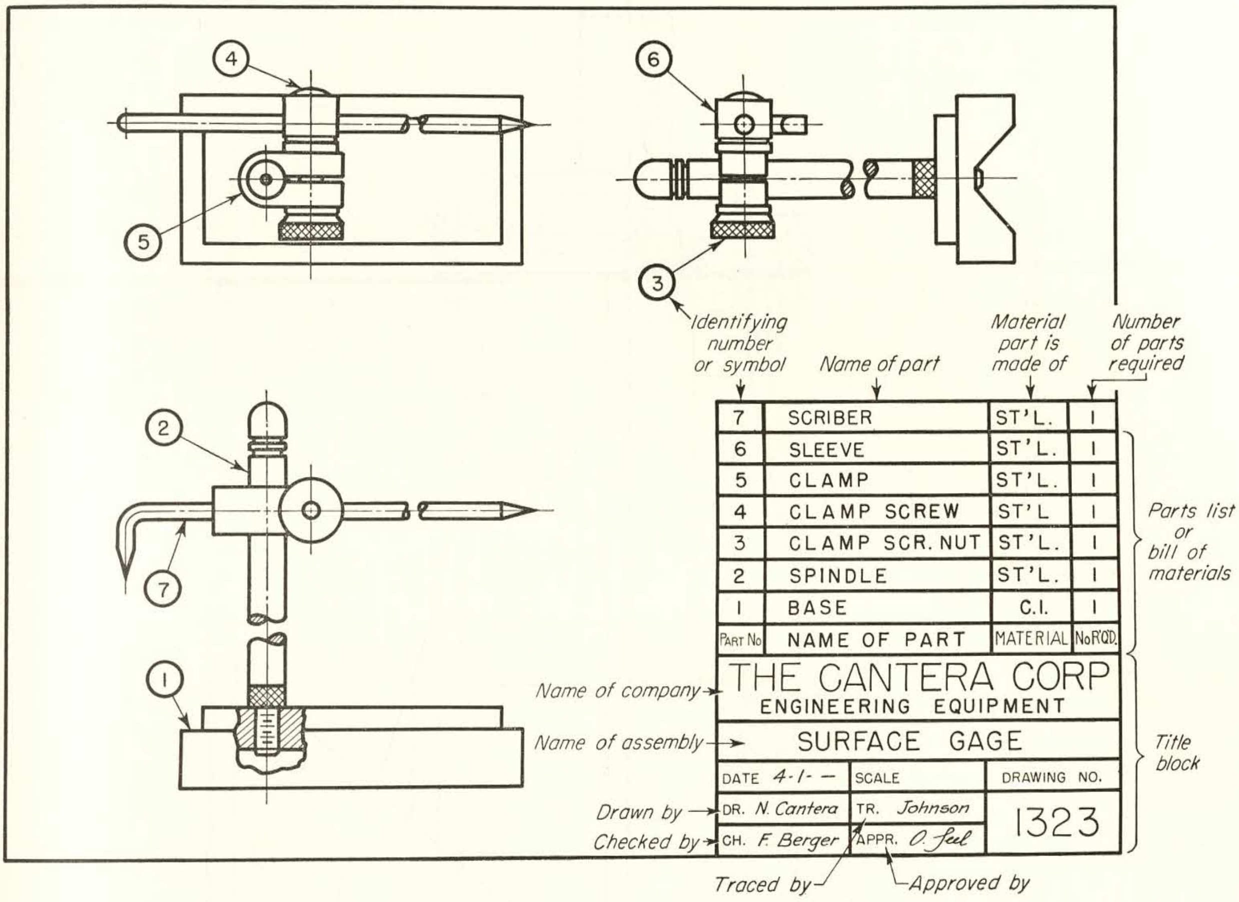


Fig. 13-9. Identification of parts.

tion, a working-drawing assembly may be prepared. In this type of assembly, all details are completely dimensioned and identified by notes giving the necessary manufacturing and assembly procedures, and separate detail drawings are not made (see Fig. 13-11). The views shown should be adequate and should not require additional detail drawings for further dimensioning. Unit and subassemblies of mechanisms that are to be produced in limited quantities are often shown in this manner because the drawings are needed by only a few persons. A title block with parts list and record strip should be shown on the same sheet.

13-8. Outline assembly (installation assembly). An outline-assembly drawing shows only the external contours and shape-describing lines of a structure or mechanism. Because it is often employed as a guide for erection or installation, it is also known as an "installation assembly." Only the dimensions that show the over-all size of the external surfaces are given on the drawing (see Fig. 13-12).

13-9. Check assembly. In order to make sure that details designed for an assembly are of the proper size and material and will fit together correctly, a check assembly is sometimes prepared. All the parts are drawn accurately, with instruments, to their exact size and in their true relationship to other parts in the assembly. The details are scaled carefully but are not dimensioned. Once the check assembly has fulfilled its purpose, it may be used as a general assembly.

13-10. Display assembly. If an assembly drawing is to be used for display or catalogue purposes, a display assembly is usually prepared (see Fig. 13-13). This is an attractive pictorial with line or halftone shading to give the effect of depth and perspective, employing color if cost is not an important consideration. Descriptive text material in addition to identifying notes may accompany

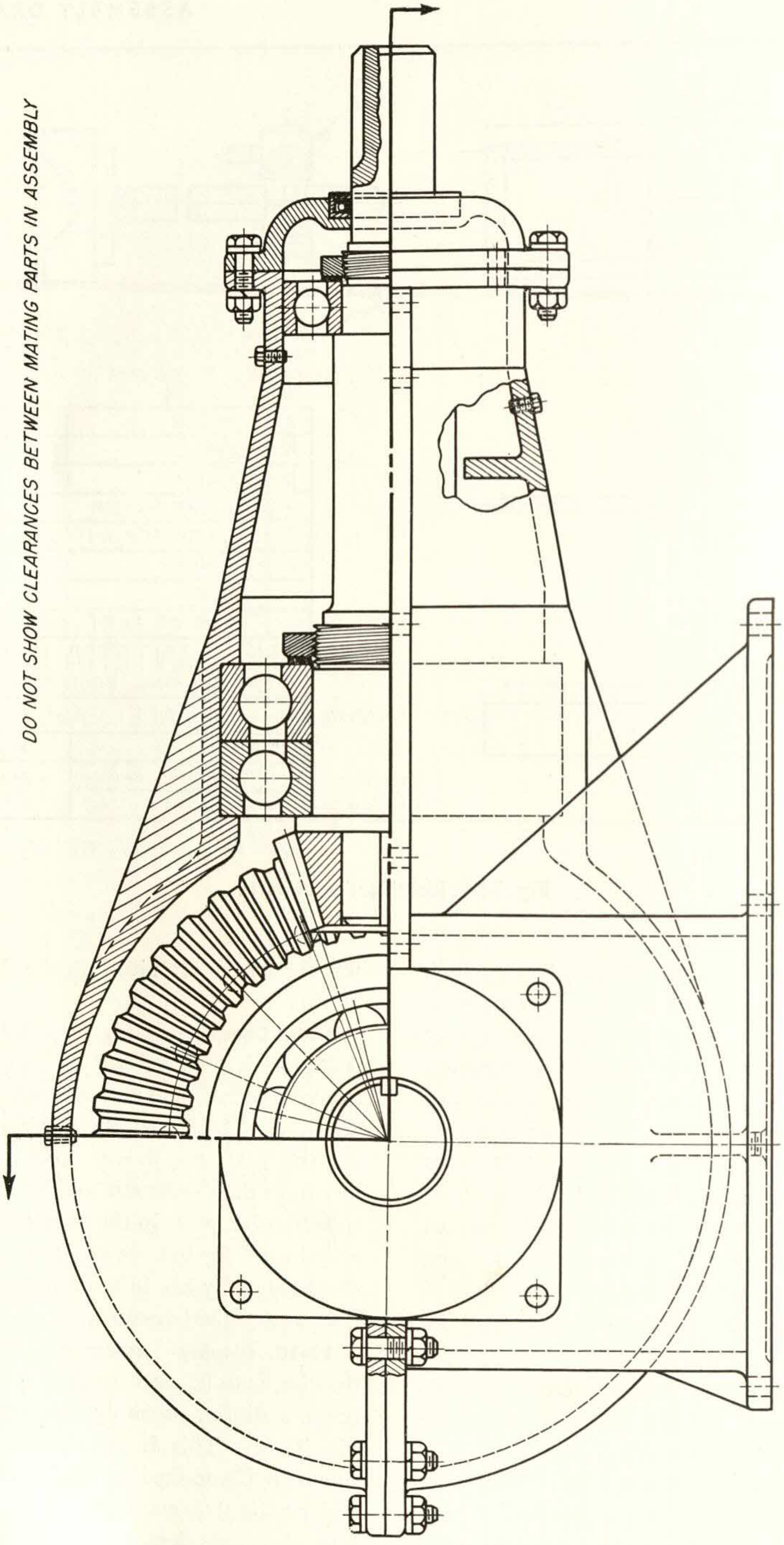


Fig. 13-10. Main view from a unit assembly drawing (reducer unit).

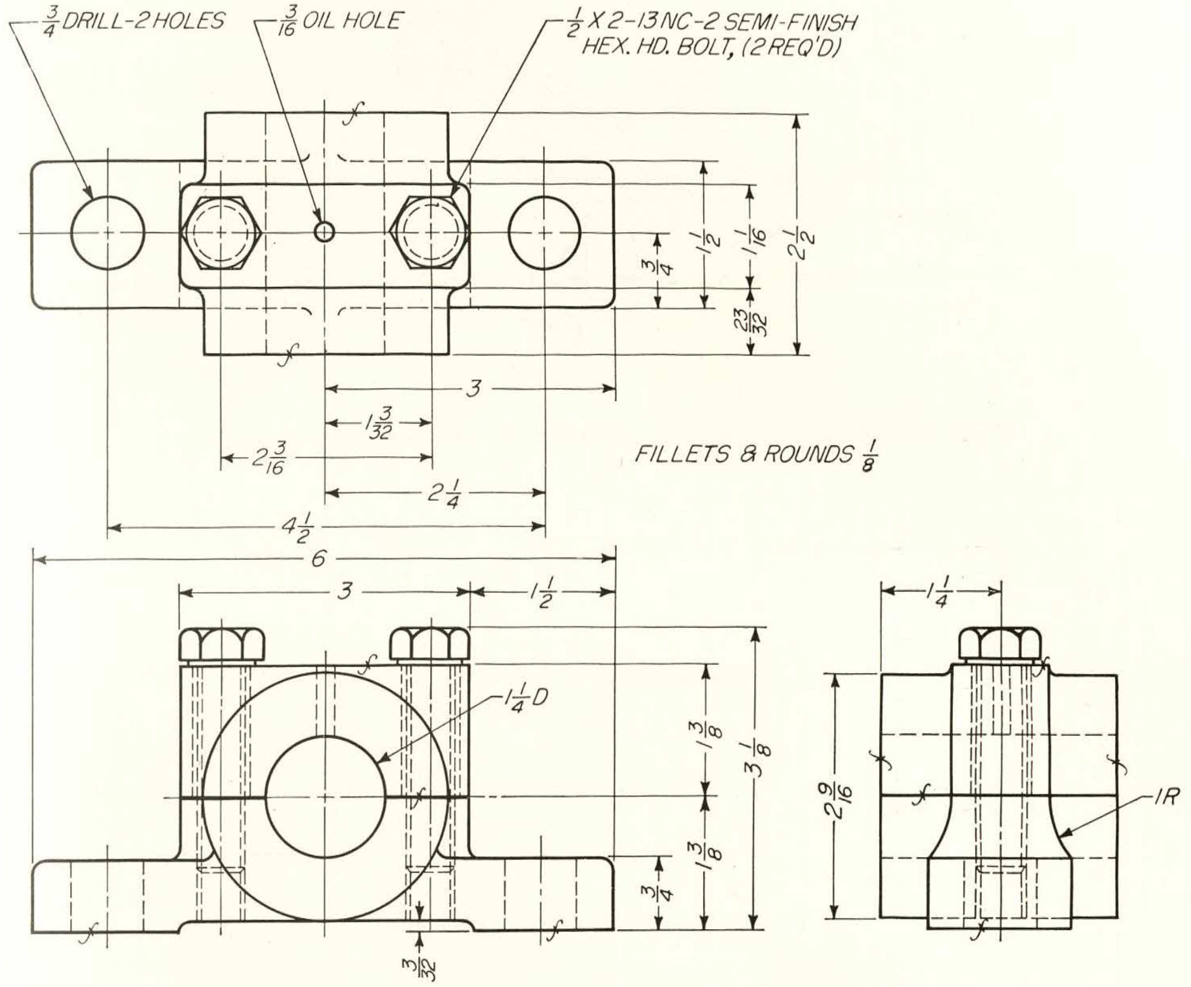


Fig. 13-11. A working-drawing assembly (bearing-bracket unit).

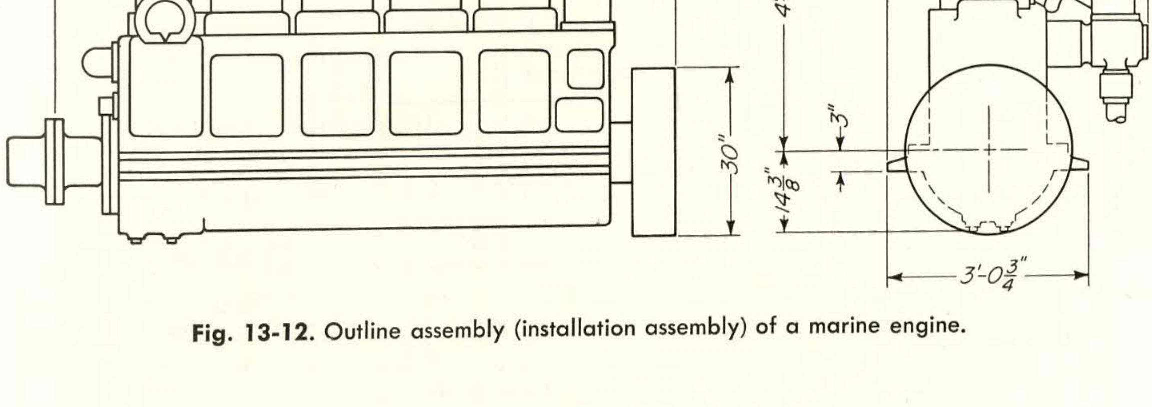


Fig. 13-12. Outline assembly (installation assembly) of a marine engine.

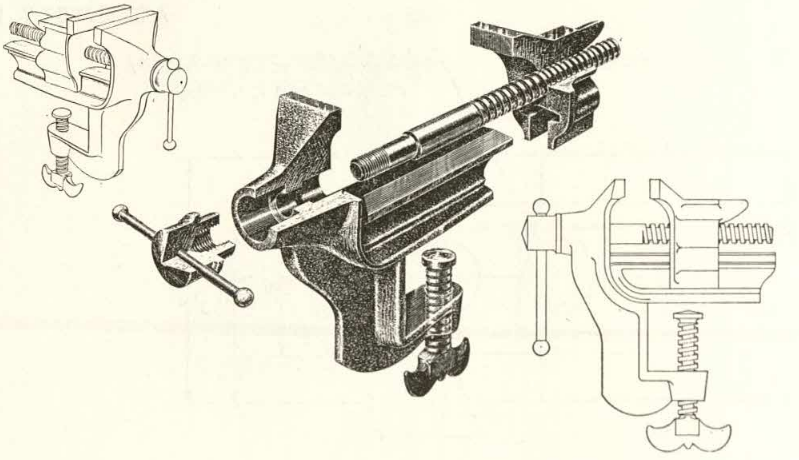


Fig. 13-13. Pictorial display assembly (often called an "exploded drawing").

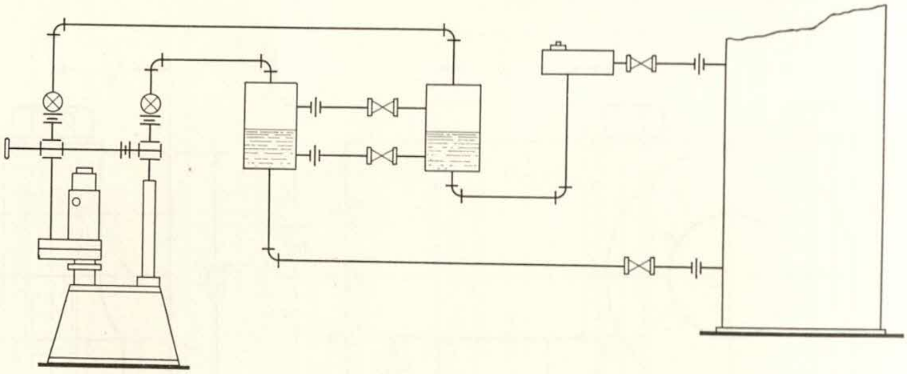


Fig. 13-14. Plumbing-diagram drawing.

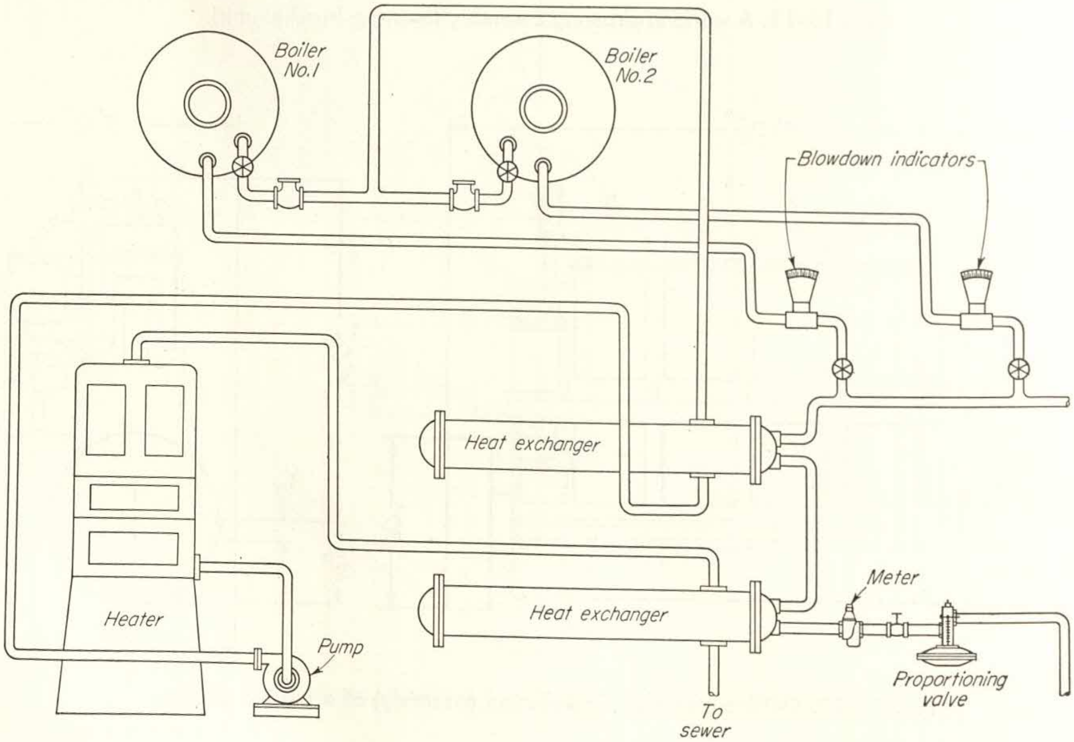


Fig. 13-15. Plumbing semipictorial drawing.

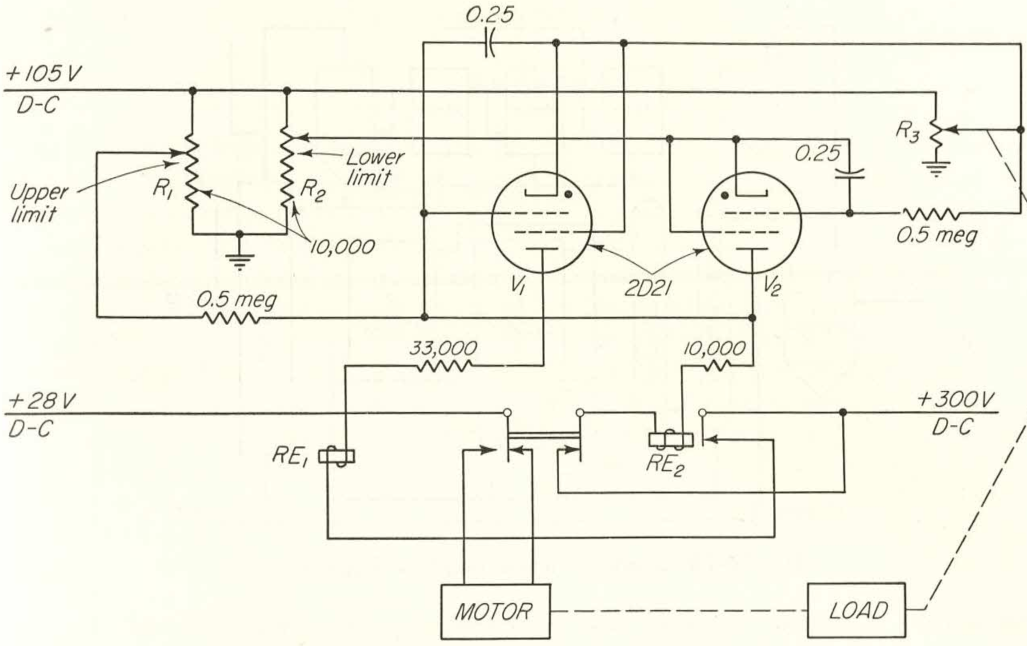


Fig. 13-16. Electrical-diagram drawing. (*From Keith Henney and James D. Fahnestock, "Electron Tubes in Industry," McGraw-Hill, New York, 1952.*)

the drawing. A pictorial display assembly is more easily understood and far more convincing to a person not trained in the reading of orthographic presentations.

13-11. Diagram drawing. A type of drawing that is very useful in the plumbing, electrical, and building industries is the diagram drawing (see Figs. 13-14 to 13-16). The diagram drawing is prepared either pictorially or orthographically and need not necessarily be drawn to scale. The draftsman should use the standard conventional symbols to represent details of piping, circuits, etc. (see the Appendix, Tables 28 to 33). If dimensions are to be given, the figures must indicate the true distances between the points measured. Any notes necessary for the assembly of the details or construction of the unit, together with the kind and sizes of the parts required, are included in the drawing. Diagram drawings are employed frequently in architectural engineering and in construction work (see Fig. 13-17).

The chemical engineer frequently has to construct flow diagrams similar to the one shown in Fig. 13-18. In such diagrammatic representations, the engineer is primarily concerned with the operational cycle and the placement of the necessary equipment for various processes such as mixing, grinding, dying, distillation, sedimentation, and evaporation. Simple outlines of forms similar in shape to the object may be used to indicate the various pieces of equipment, and the drawing need not be made to scale.

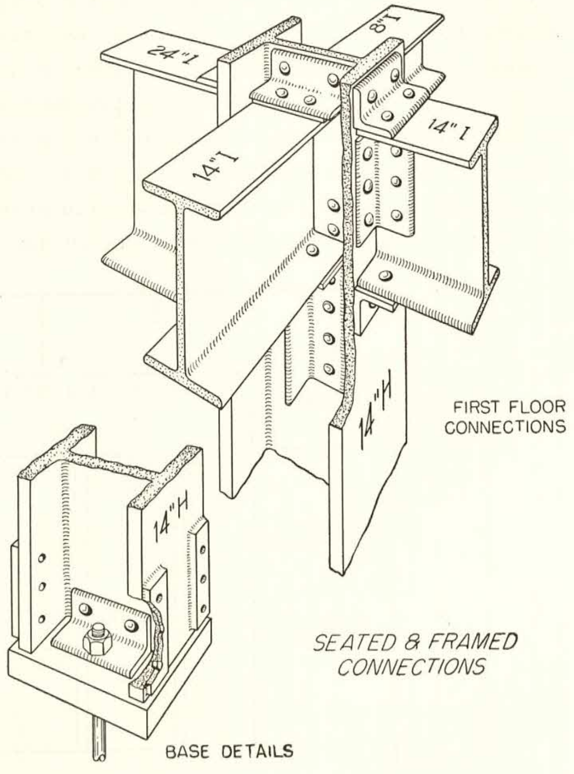


Fig. 13-17. Pictorial construction drawing (architectural engineering).

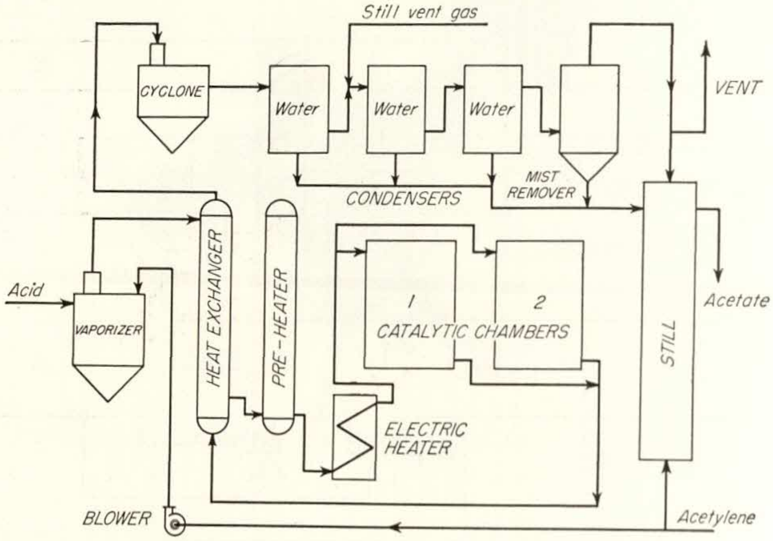


Fig. 13-18. Chemical-engineering flow diagram.

13-12. Plant-layout drawing. Because the plant engineer is often better acquainted with the particular needs of his organization than the architect, to him may fall the task of preparing the layout for a new factory or processing plant. If existing facilities are to be added to or revised, he will also be called upon to offer his advice. A successful plant layout is the result of careful analysis of process and flow sheets, manufacturing procedures, machine information, materials handling, work areas, and aisle and storage space. The building plans must be carefully scrutinized before decisions can be made concerning the arrangement and allotment of the available floor space. A layout drawing is prepared to scale and should show the outline of the building, the locations of aisles, work areas, and rooms, and the positions occupied by the various machines, conveyors, etc. (see Fig. 13-19). The scales employed range from $\frac{1}{32}$ to $\frac{1}{4}$ in. to the foot, depending upon the size of the drawing. The accepted conventional symbols for materials of construction are used, and doors, windows, walls, etc., are shown as the architect would draw them (see Table 33 in the Appendix).

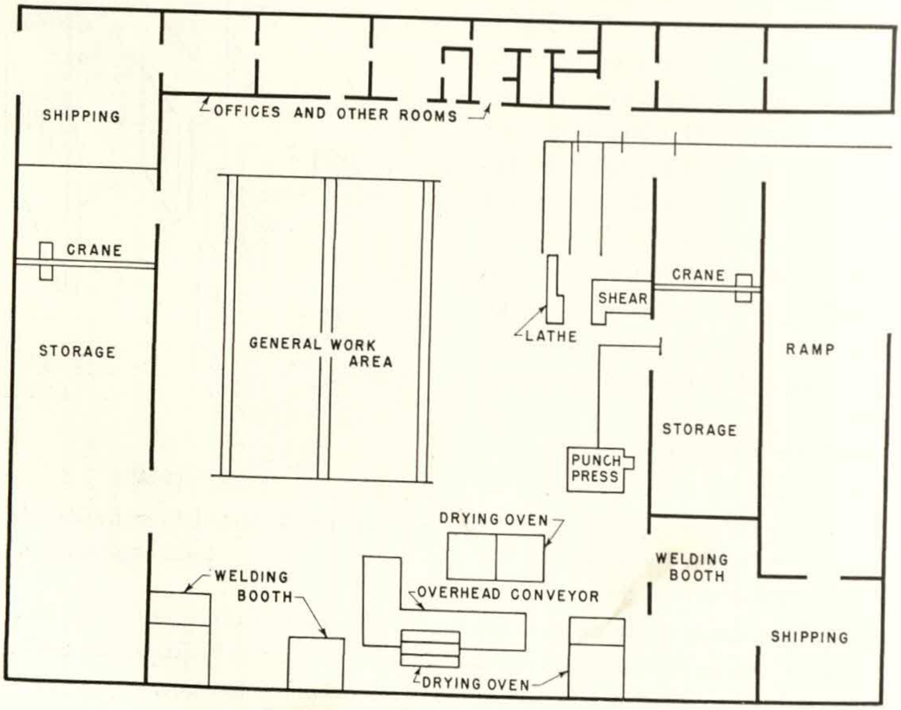


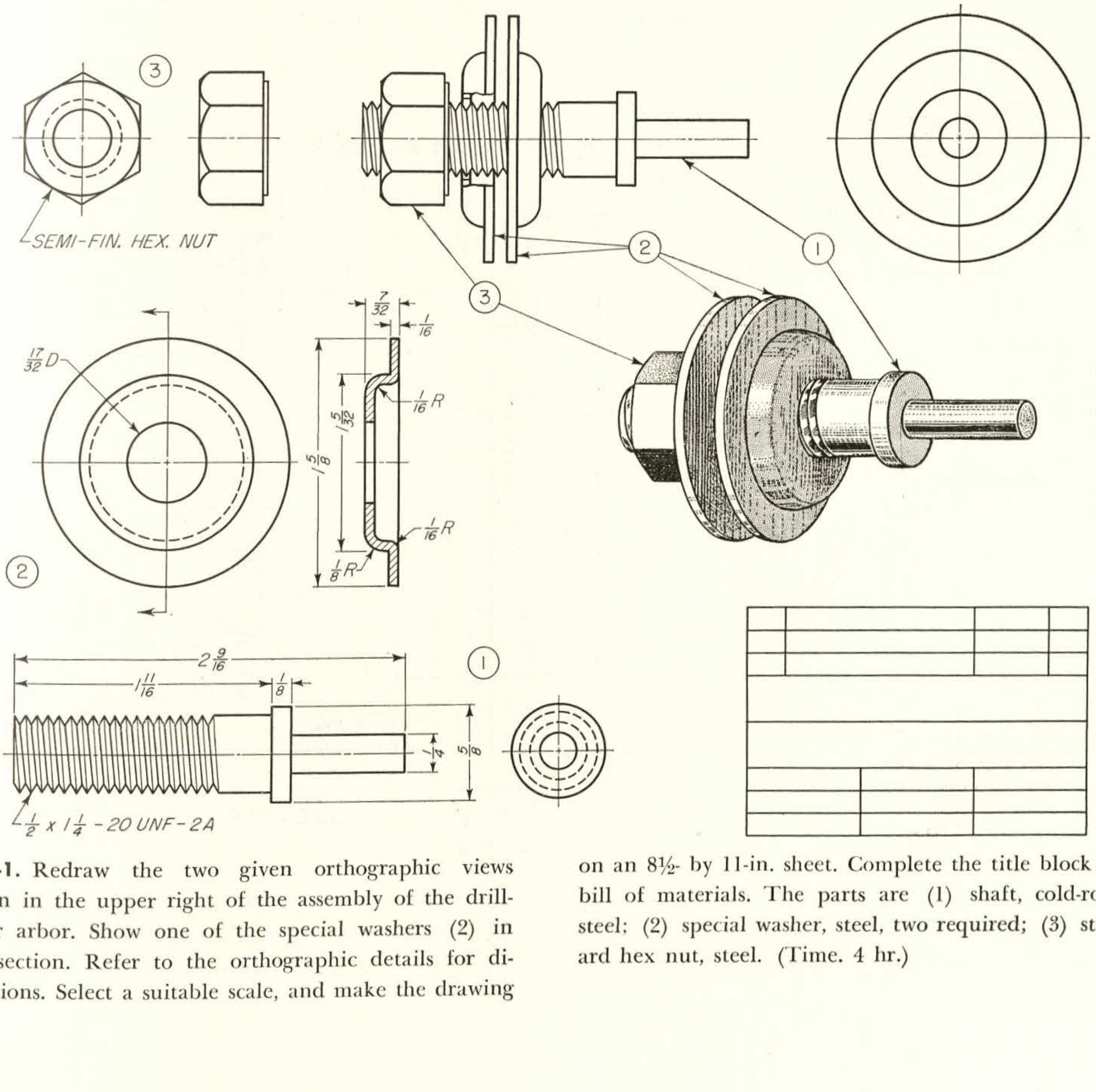
Fig. 13-19. Plant-layout drawing.

PROBLEMS

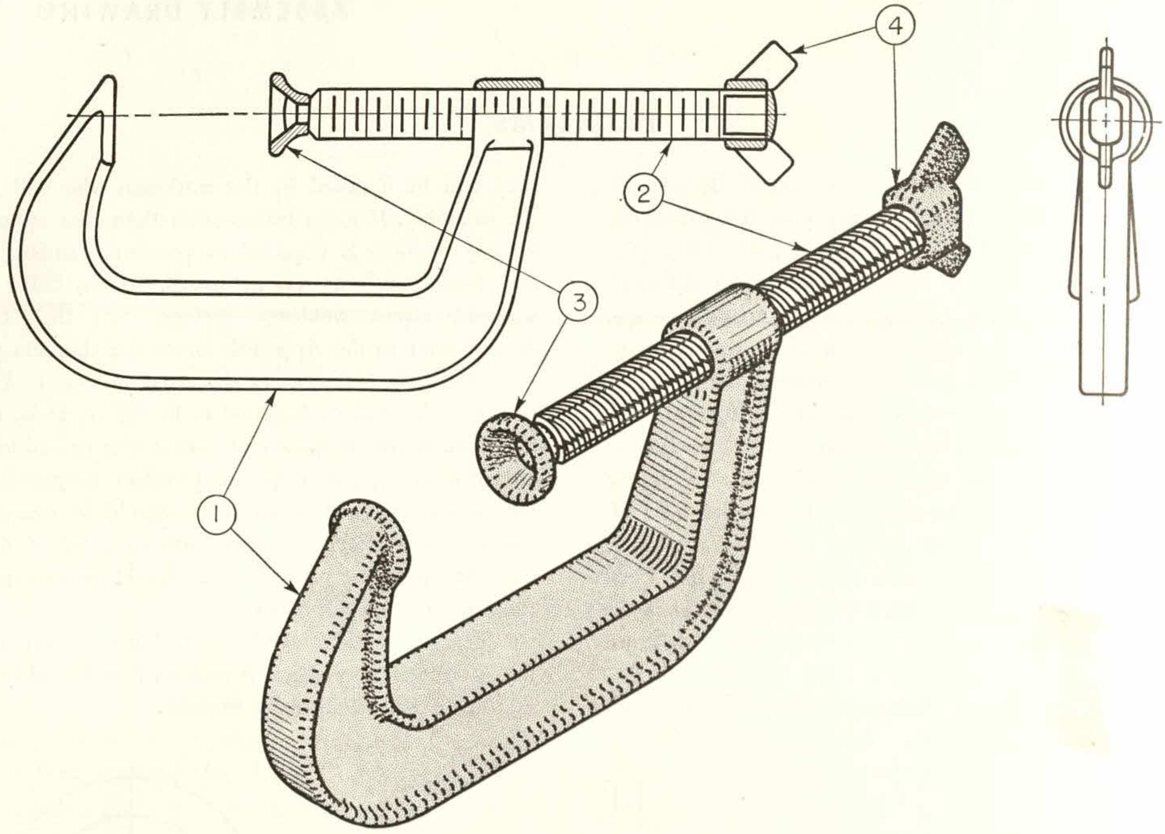
The following problems have been especially selected to give the student practice in applying the principles of assembly drawing set forth in this chapter. For Probs. 13-1 to 13-25, the student need have no previous knowledge or training in the principles of mechanical design, nor will he find it necessary to refer to handbooks or to other texts in order to be able to produce the drawings required. The pictorial views and the orthographic details are to be used in conjunction to produce the assembly. In the pictorial views, it should be noted that a missing dimension on one part may be satisfied by a dimension appearing on its mating part. For instance, when the thread specification on one part has been shown, it may have been omitted from the hole it fits into. The case may be the same with mating slot forms, etc.

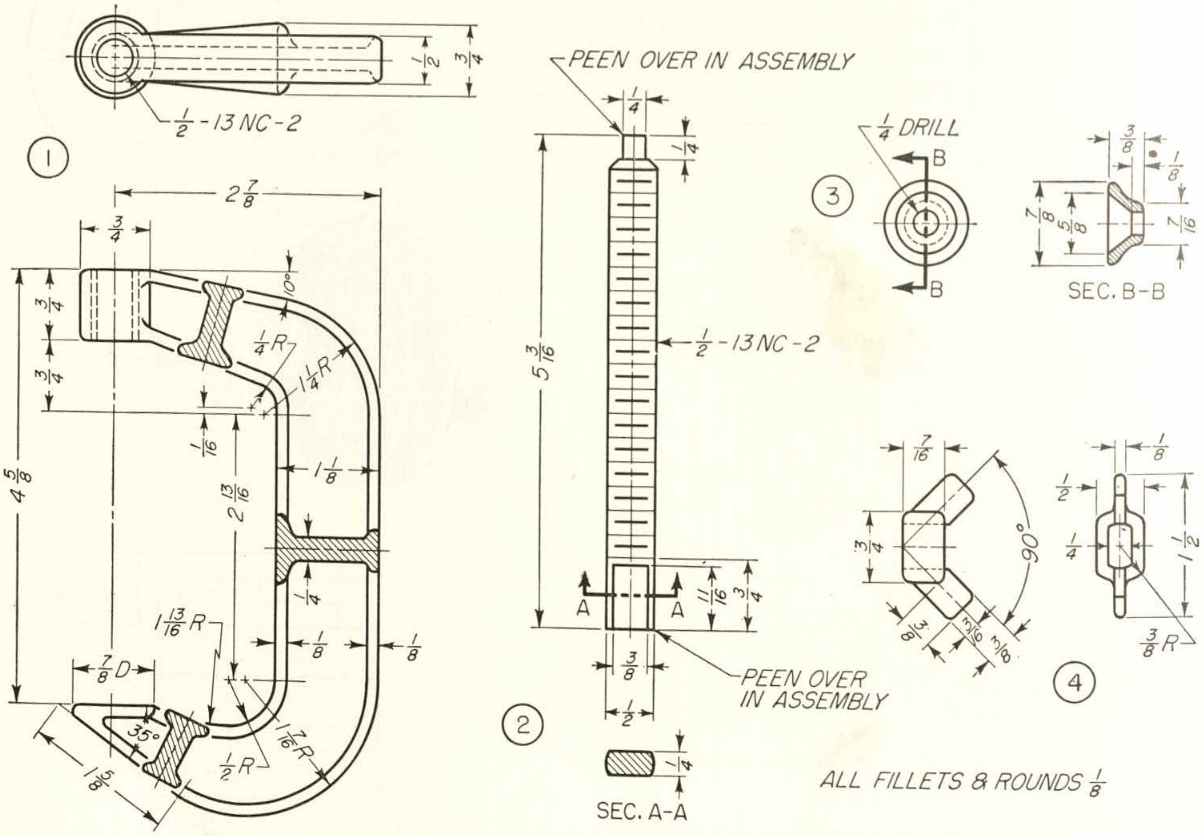
The parts should be numbered in the order in which they will be handled by the workman who will make the assembly. If more information than that appearing in the problem is required to produce standard parts and forms, such as screw threads, screws, bolts, nuts, washers, rivets, weldings, springs, etc., the student should refer to the Appendix or to the chapters where the particular features are discussed in detail. All the problems have been designed to fit 8½- by 11-in. or 11- by 17-in. sheets if drawn at actual size or reduced or enlarged as suggested in the problem assignments. A title block and bill of materials should be drawn and filled in completely for each problem. Screw threads conforming to the unified series should be indicated by their unified specifications.

Wherever a pictorial alone is shown as a problem, the instructor may assign it either as an assembly problem or as a detail-drawing exercise.

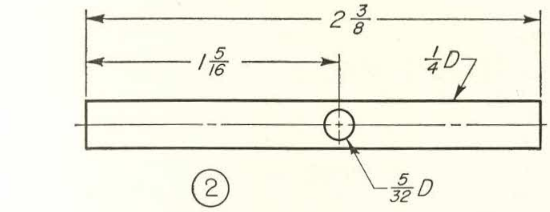


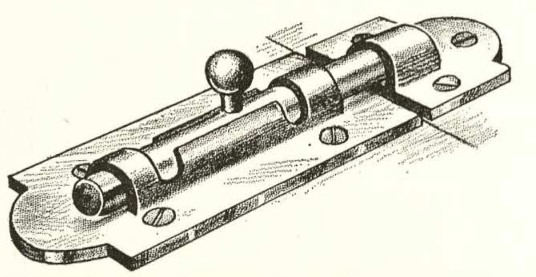
13-1. Redraw the two given orthographic views shown in the upper right of the assembly of the drill-auger arbor. Show one of the special washers (2) in full section. Refer to the orthographic details for dimensions. Select a suitable scale, and make the drawing on an 8½- by 11-in. sheet. Complete the title block and bill of materials. The parts are (1) shaft, cold-rolled steel; (2) special washer, steel, two required; (3) standard hex nut, steel. (Time. 4 hr.)

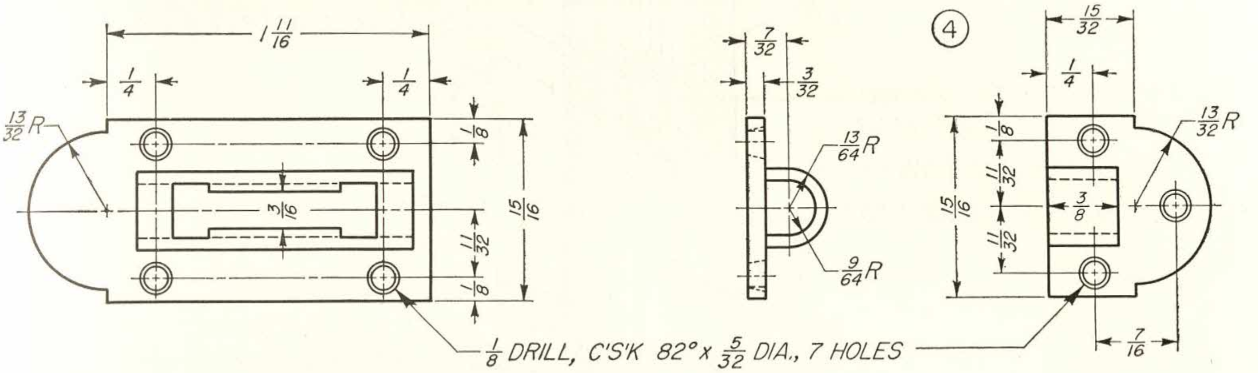


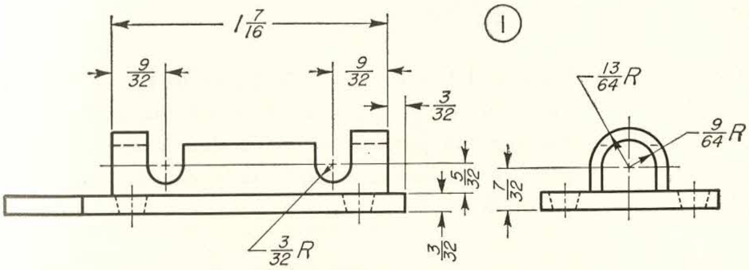


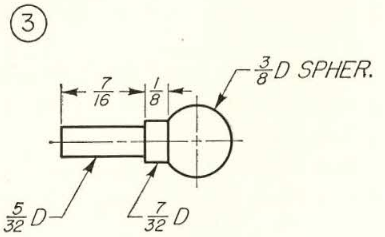
13-2. Redraw the two given orthographic assembly views (shown with the pictorial of the C clamp) on an 11- by 17-in. sheet. Refer to the details for the dimensions. The assembly consists of (1) cast-iron clamp jaw, (2) steel adjusting screw, (3) cast-iron swivel ring, and (4) cast-iron wing nut. (Time. 5 hr.)





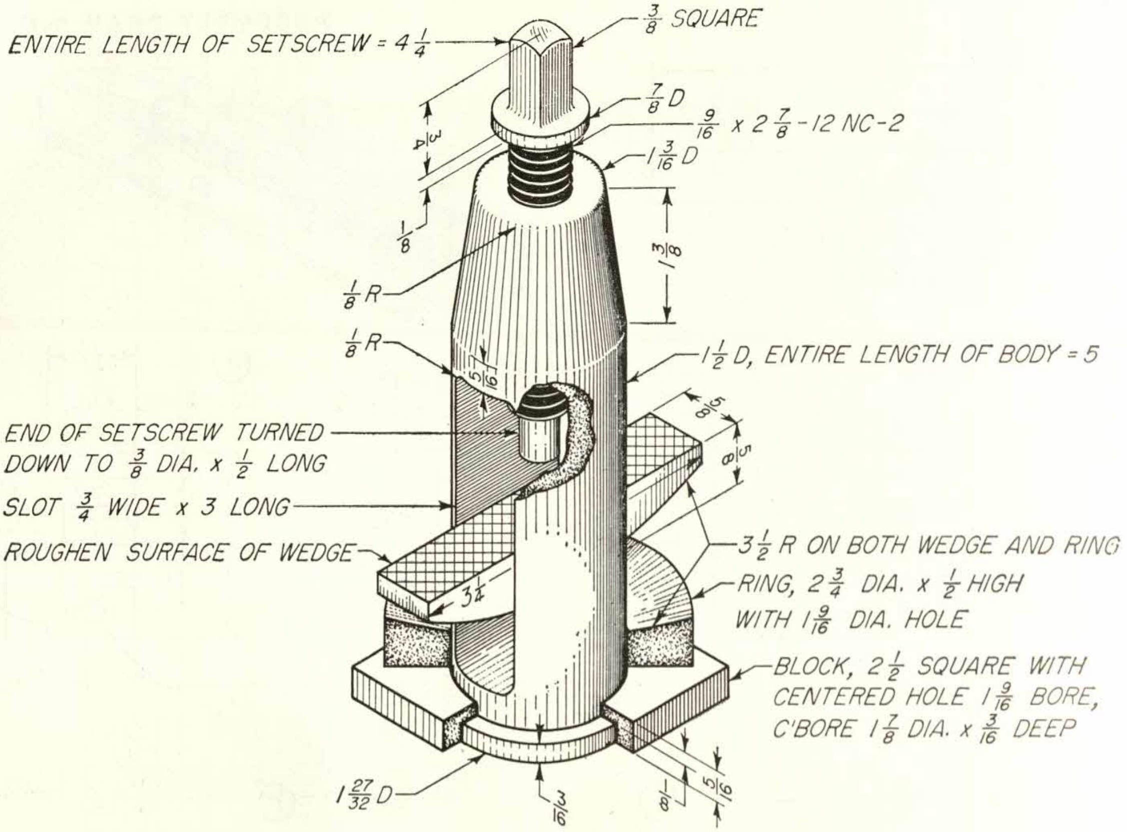






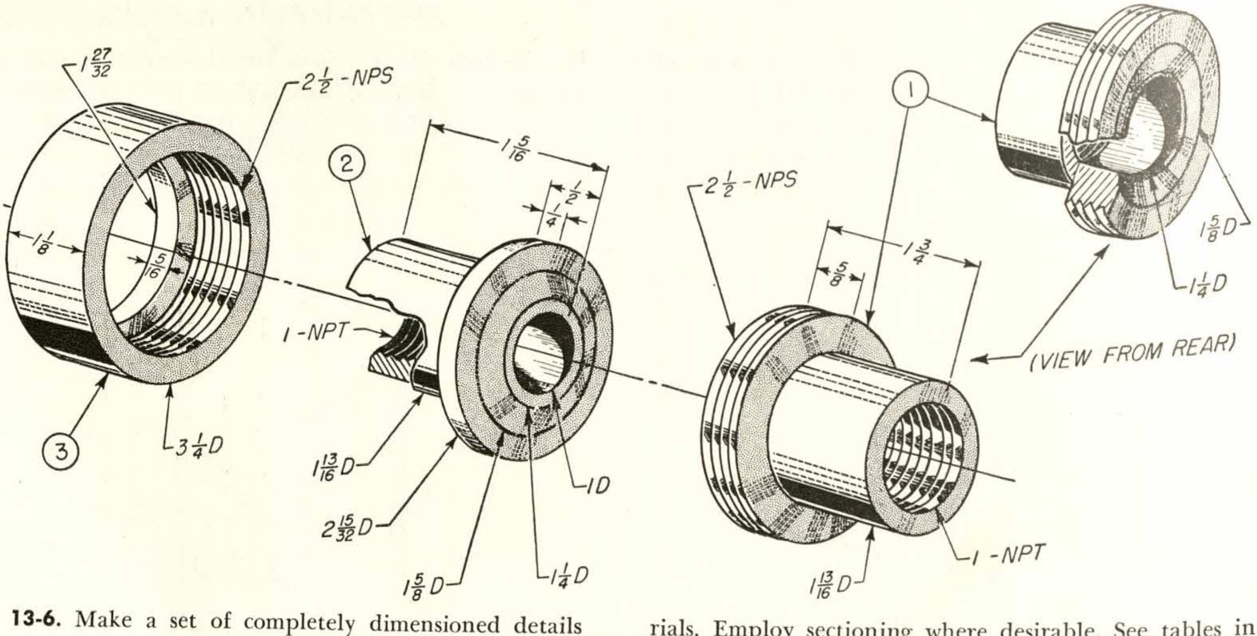
PEEN OVER END OF KNOB IN ASSEMBLY

13-3. Make a two-view general-assembly drawing of the sliding bolt lock. Show the assembly double size on an 8½- by 11-in. sheet. Use sectioning where desirable. Include over-all dimensions, but do not dimension the individual details. The parts are all brass and consist of (1) bed, (2) bolt, (3) nob, and (4) end piece. Show a title block and bill of materials. (Time. 4 hr.)



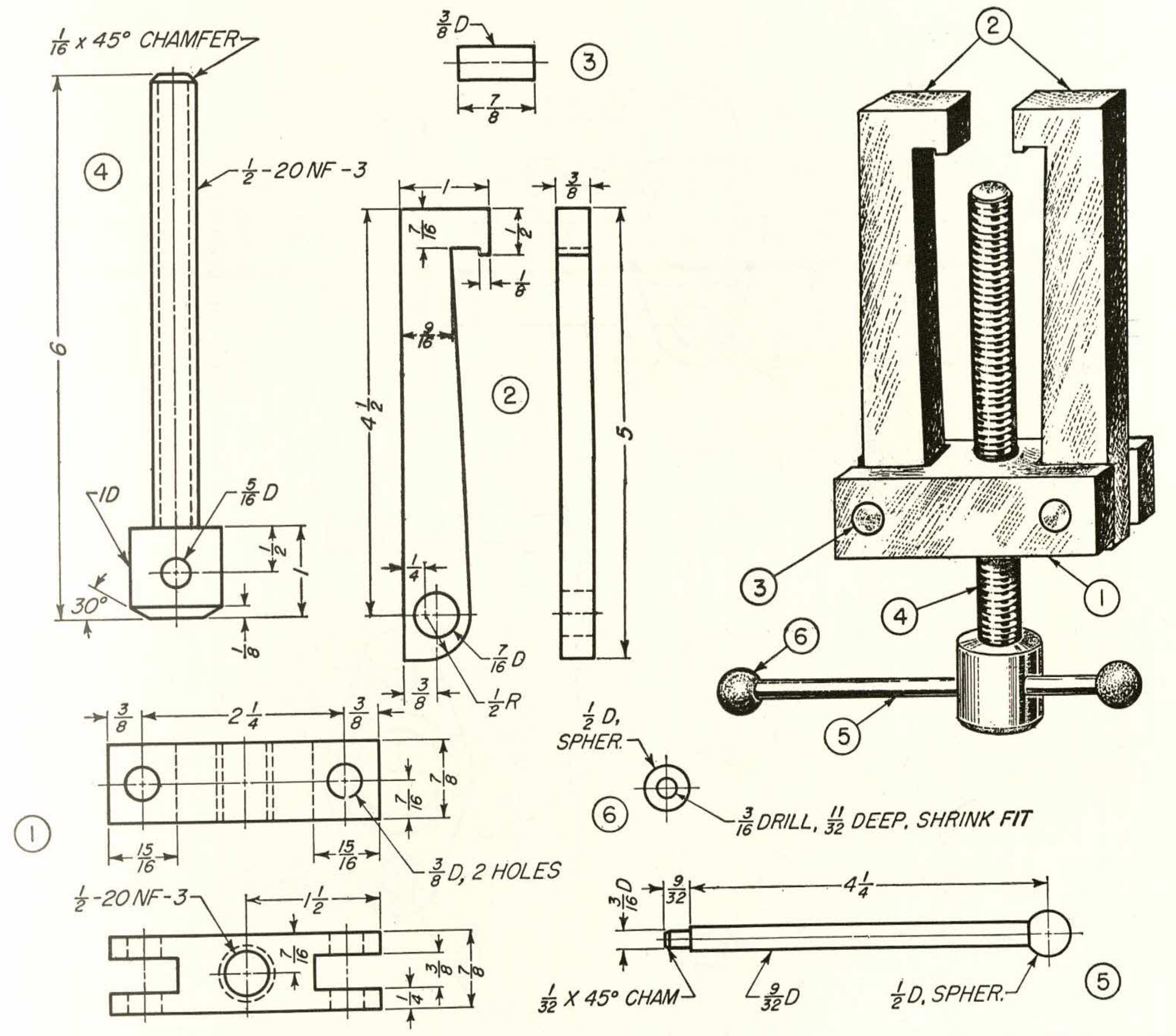
13-4. Make a set of detail drawings of the tool post, completely dimensioned, on an 11- by 17-in. sheet. (Time. 7 hr.)

13-5. Make a two-view general-assembly drawing of the tool post on an 8½- by 11-in. sheet. Include a title block and bill of materials. Refer to the pictorial for the names of the parts, all of which are made of steel. Number the parts in order of their assembly. Section parts as desirable. Include only over-all dimensions. (Time. 5 hr.)

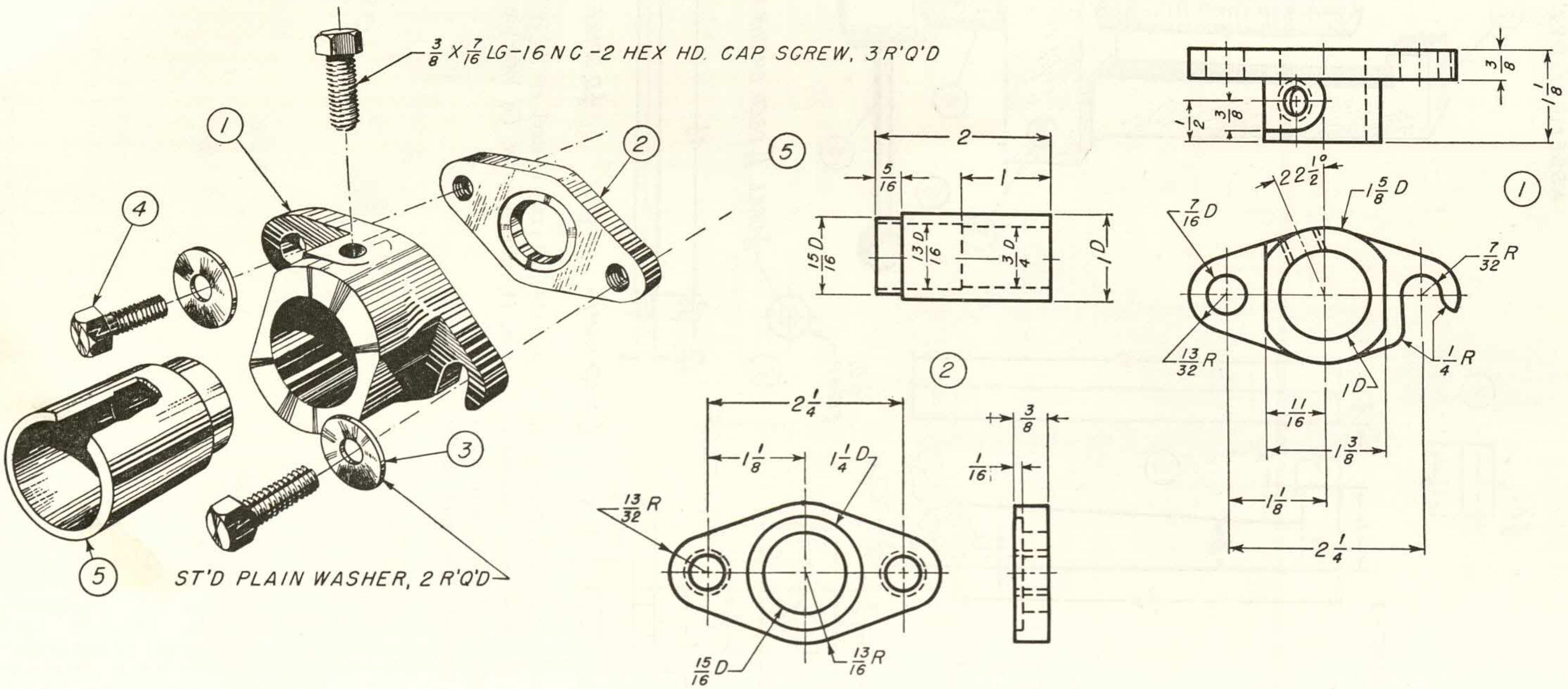


13-6. Make a set of completely dimensioned details of the Dilecto union on an 8½- by 11-in. sheet. (Time. 5 hr.)

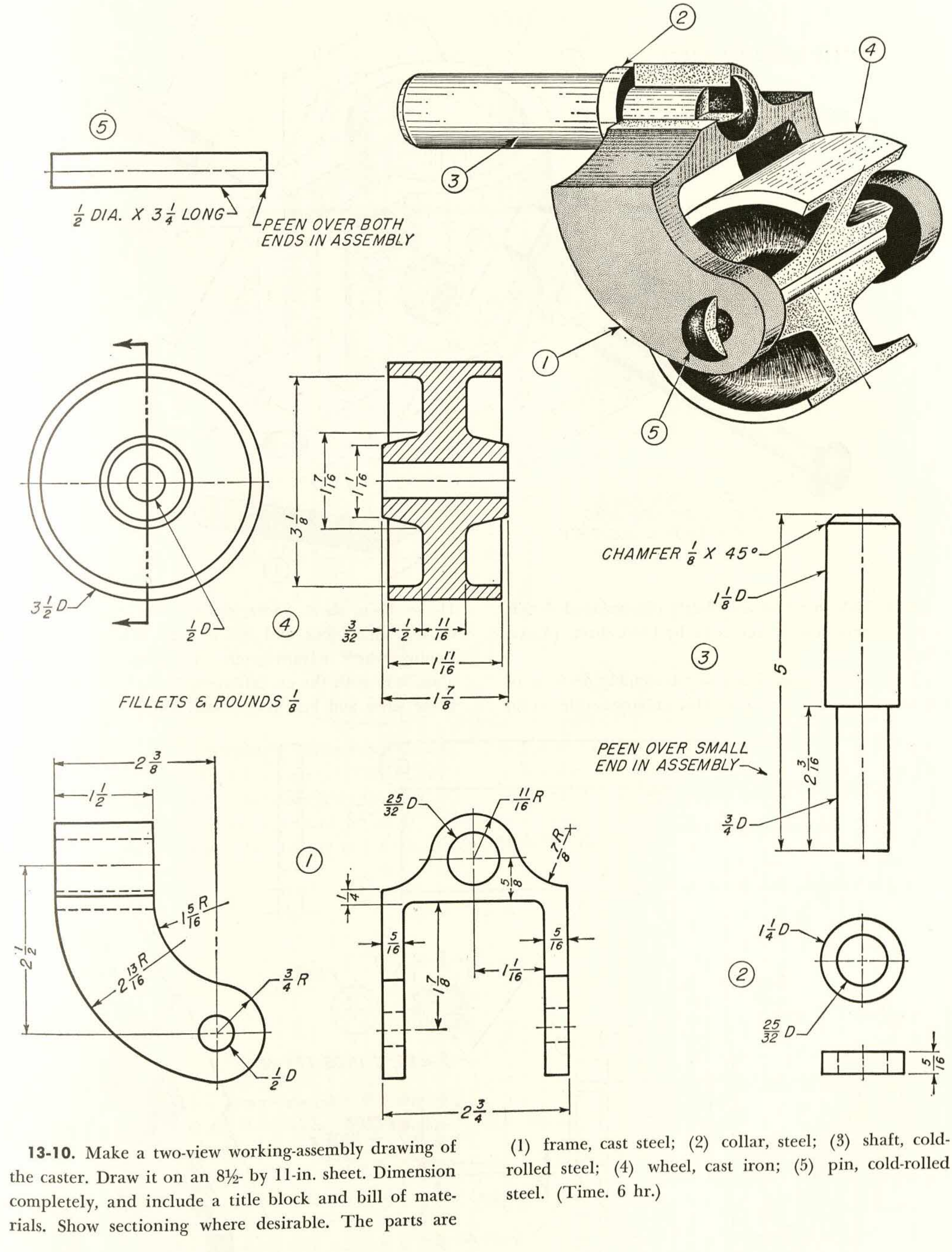
13-7. Make a two-view working-assembly drawing of the Dilecto union on an 8½- by 11-in. sheet. Dimension all details, and include a title block and bill of materials. Employ sectioning where desirable. See tables in the Appendix for information on pipe threads. Draw the threads in detail, schematically, or simplified according to the principles outlined in Chap. 12. The parts are made of fiber and consist of (1) connector nipple, (2) sealing ferrule, and (3) compression ring. (Time. 4 hr.)



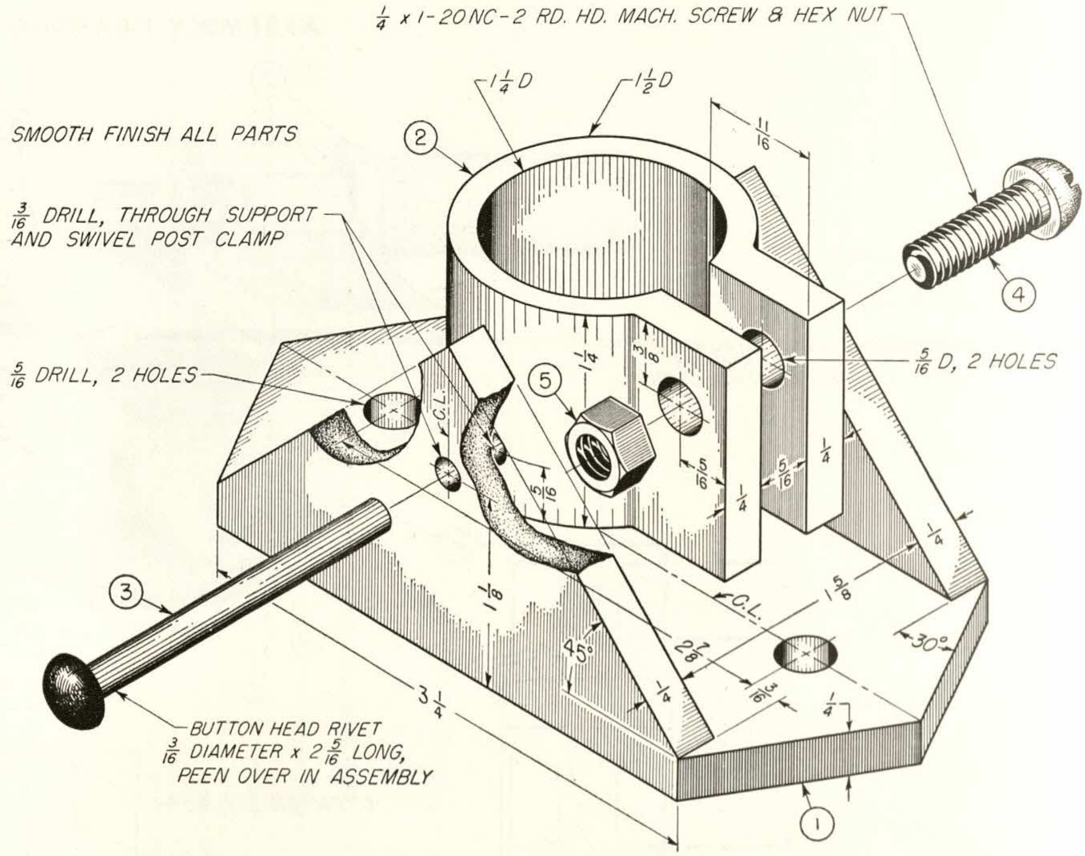
13-8. Make a two-view working-assembly drawing of the wheel puller on an 11- by 17-in. sheet. Dimension completely, and include a title block and bill of materials. Use sectioning where desirable. The parts in the assembly, all made of steel, are (1) yoke, (2) jaws, (3) pin, (4) pulling screw, (5) loose-pin handle, and (6) ball.



13-9. Make a two-view working-assembly drawing of the toolholder on an 8½- by 11-in. sheet. Dimension all details, and include a title block and bill of materials. Section where desirable. The parts are (1) body, cast iron; (2) flange, cast iron; (3) plain washer, steel; (4) standard hex-head cap screw, steel; (5) bushing, cold-rolled steel. (Time. 6 hr.)

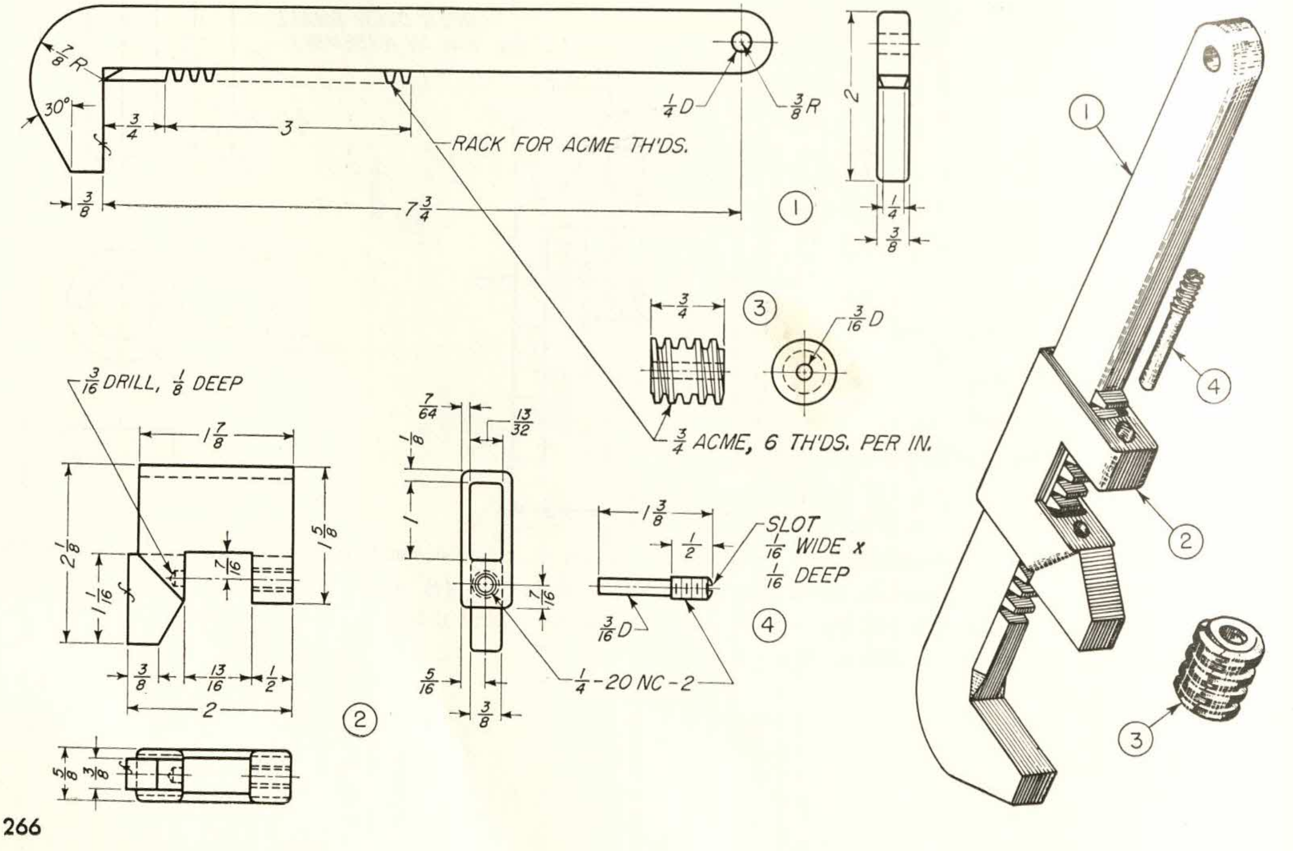


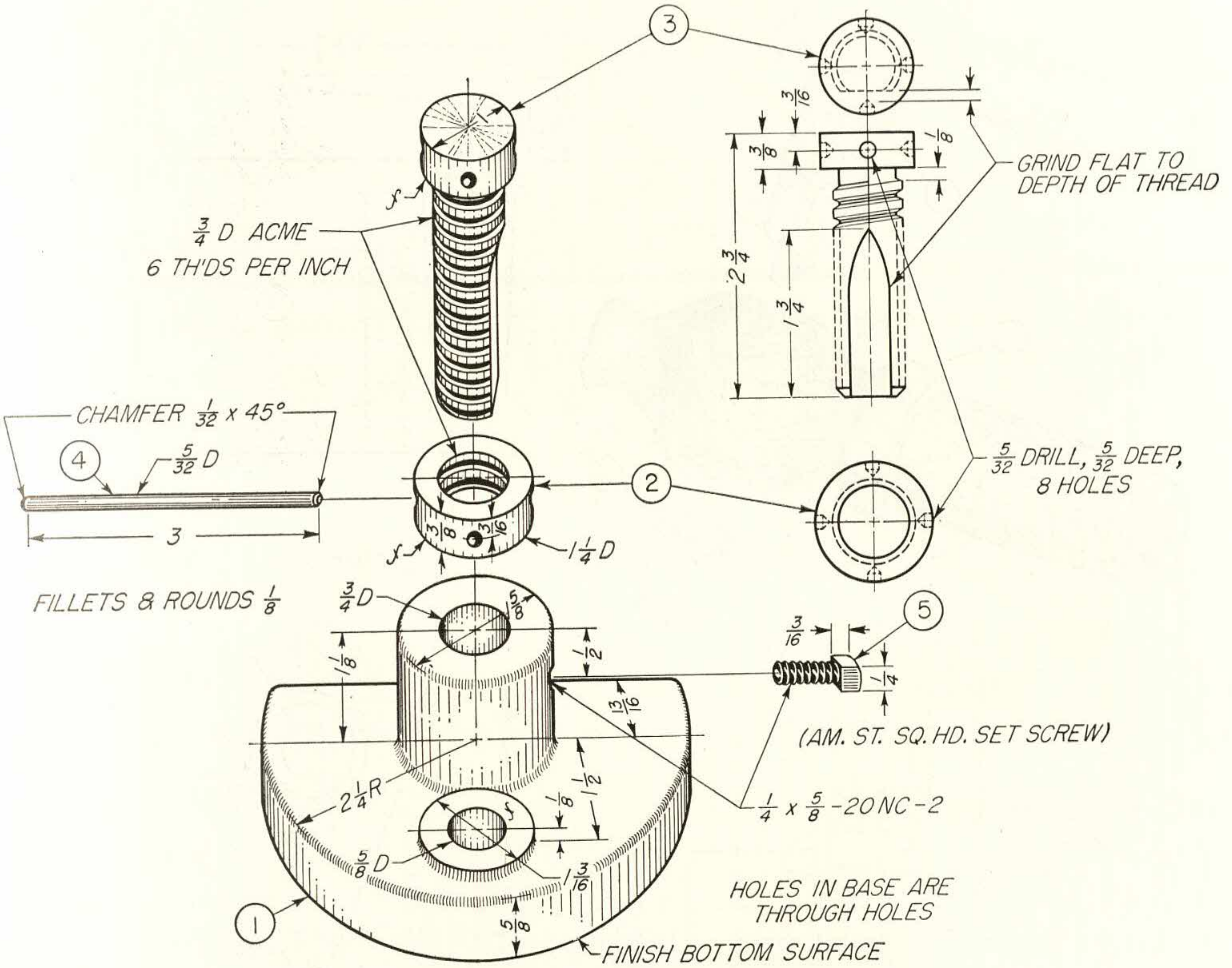
13-10. Make a two-view working-assembly drawing of the caster. Draw it on an 8½- by 11-in. sheet. Dimension completely, and include a title block and bill of materials. Show sectioning where desirable. The parts are (1) frame, cast steel; (2) collar, steel; (3) shaft, cold-rolled steel; (4) wheel, cast iron; (5) pin, cold-rolled steel. (Time. 6 hr.)



13-11. Make a set of completely dimensioned details of the antenna support on an 11- by 17-in. sheet. (Time. 7 hr.)

13-12. Make a two-view general-assembly drawing of the antenna support at a suitable enlarged scale on an 11- by 17-in. sheet. Show over-all dimensions, and include a title block and bill of materials. Employ sectioning where advantageous. All parts are made of aluminum with the exception of the standard steel machine screw and hex nut. (Time. 5 hr.)

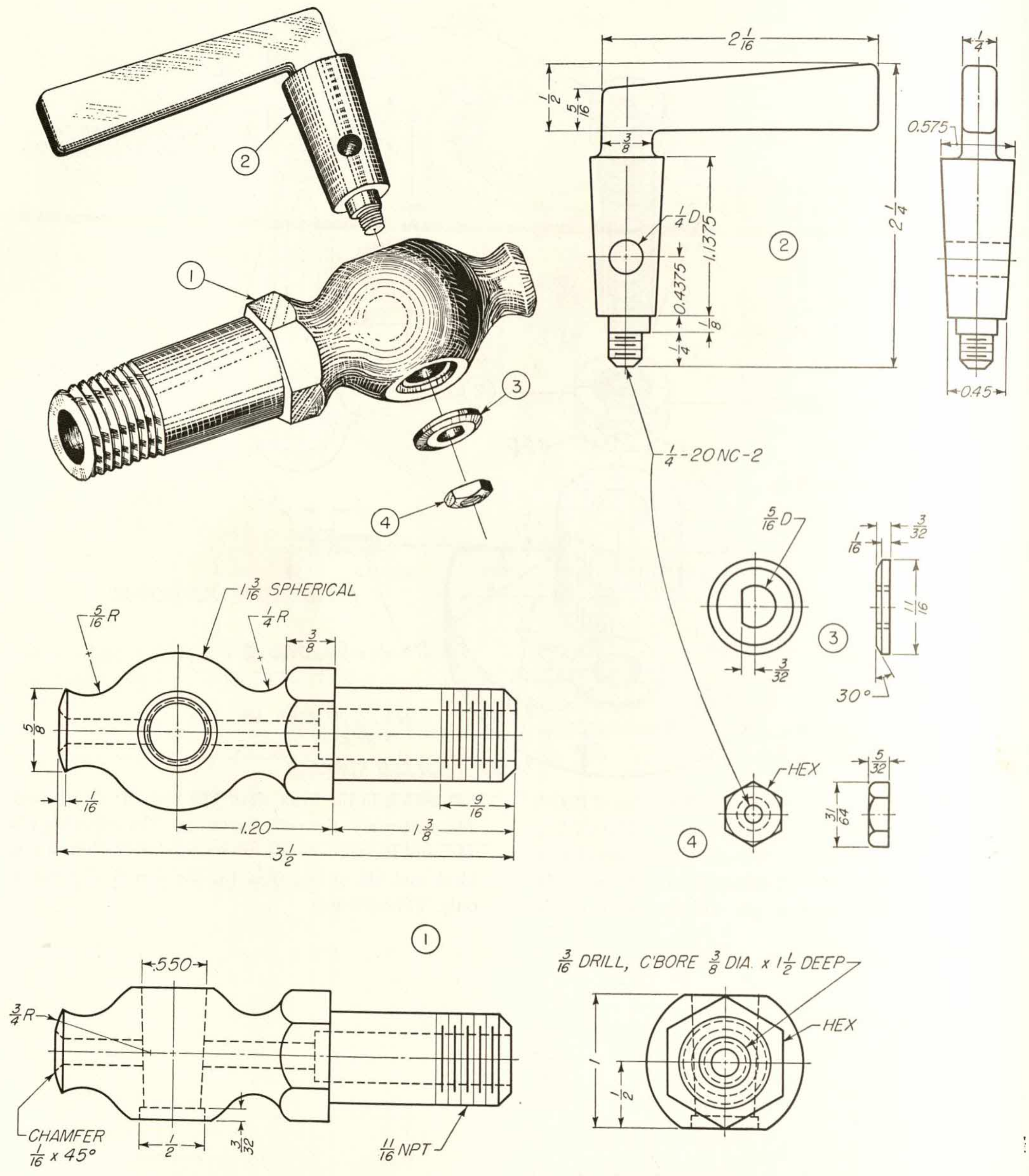




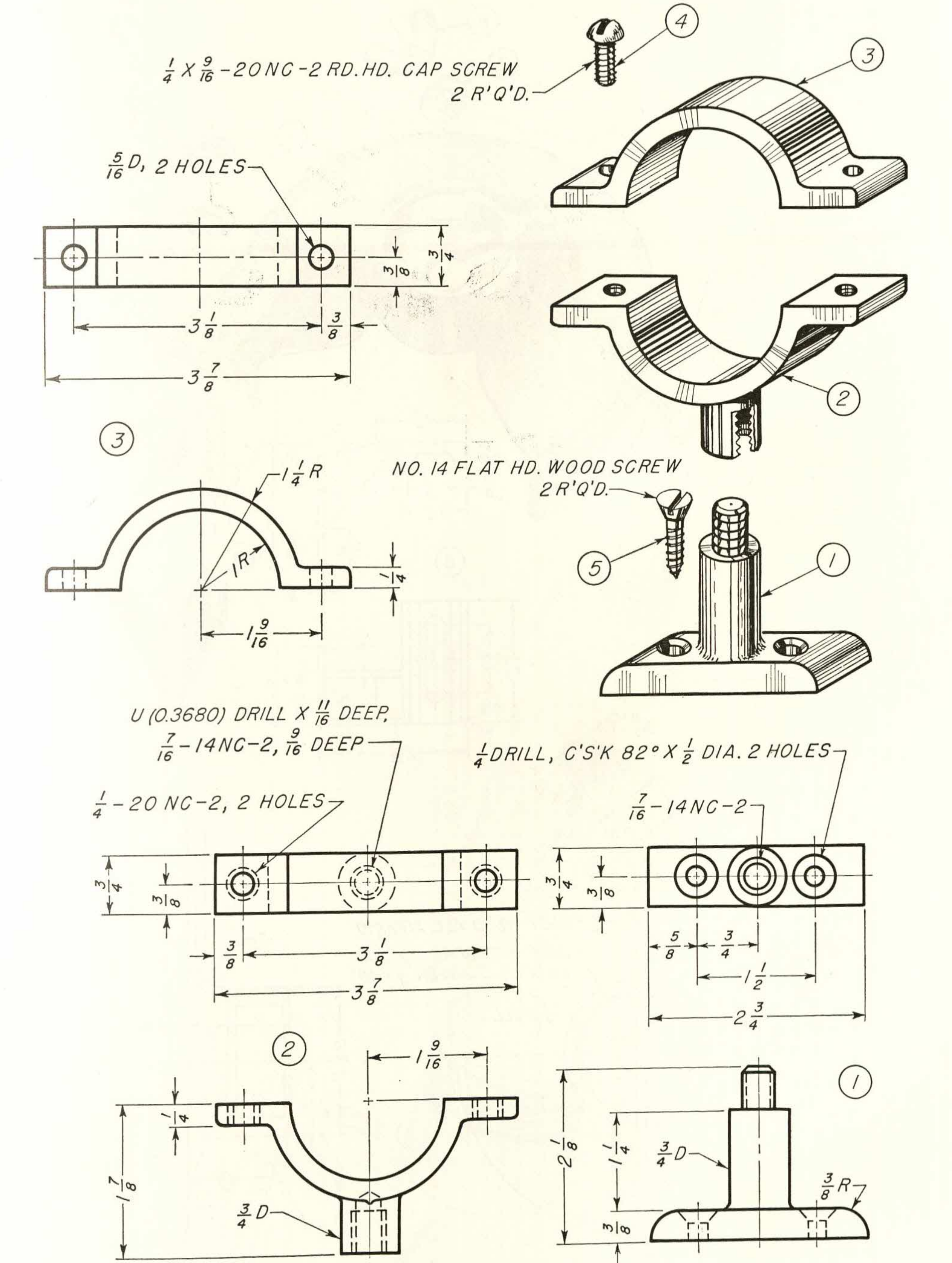
13-14. Make a set of completely dimensioned details of the table jack on an 11- by 17-in. sheet. (Time. 7 hr.)

13-15. Make a two-view general-assembly drawing of the table jack at a suitable enlarged scale on an 11- by 17-in. sheet. Show the base (1) and the collar (2) in full section in the front view. The base (1) is cast iron. The collar (2), the collar screw (3), the adjusting pin (4), and the setscrew (5) are made of steel. Show a title block and bill of materials. Include over-all dimensions only. (Time. 6 hr.)

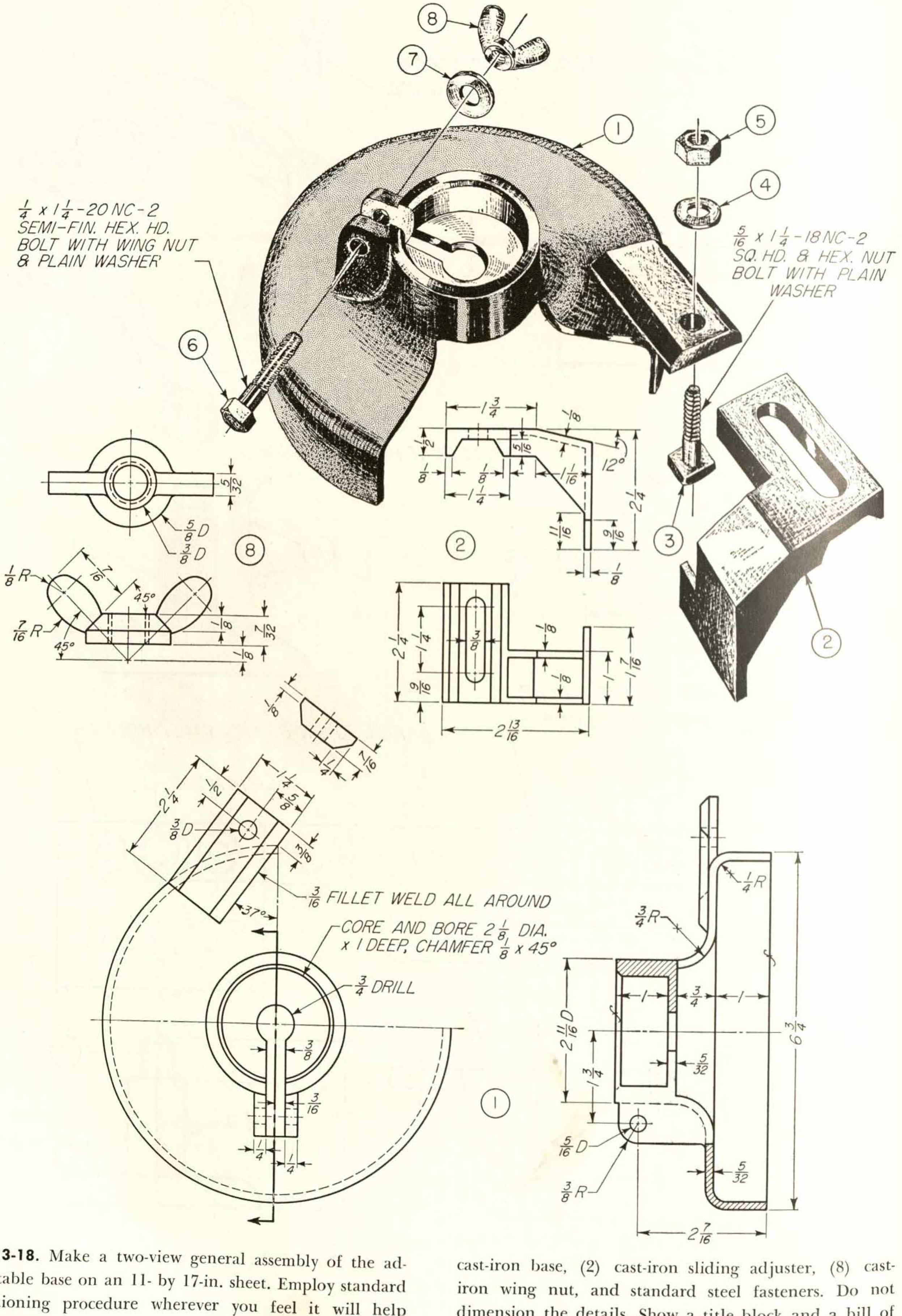
13-13. Make a two-view general-assembly drawing of the adjustable wrench on an 11- by 17-in. sheet. Employ any standard conventional or sectioning procedures that you feel will help convey the best impression of the parts in assembly. The parts, all made of steel, are (1) handle jaw, (2) movable jaw, (3) setting screw, and (4) pin. Show over-all dimensions only. Include a title block and bill of materials. (Time. 6 hr.)



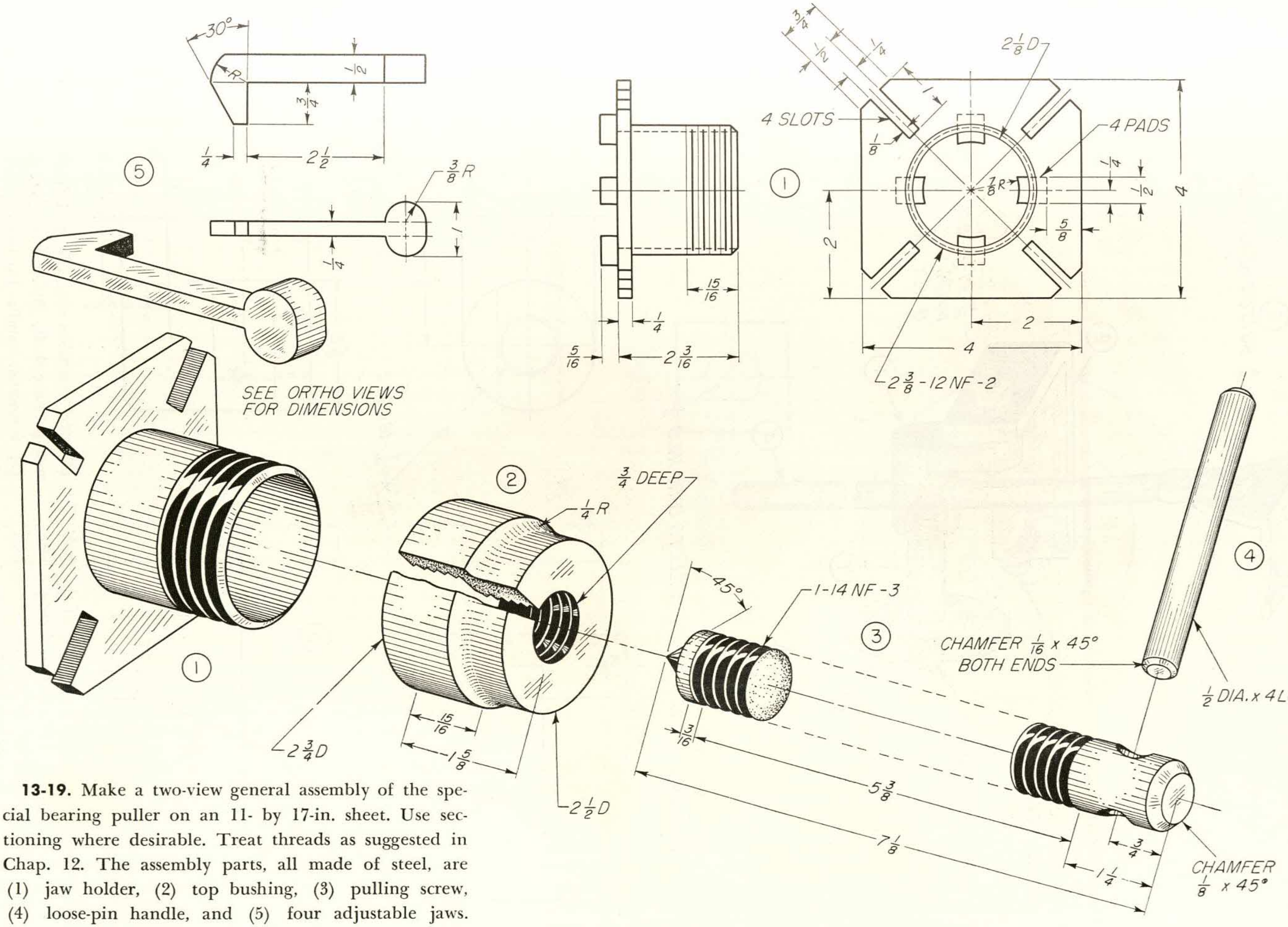
13-16. Make a two-view general-assembly drawing of the drain cock at double size on an 11- by 17-in. sheet. Show the body (1) in full section in the front view. The parts for the bill of materials are (1) body, (2) handle, (3) special washer, and (4) hex jam nut. All parts made of brass. (Time. 6 hr.)



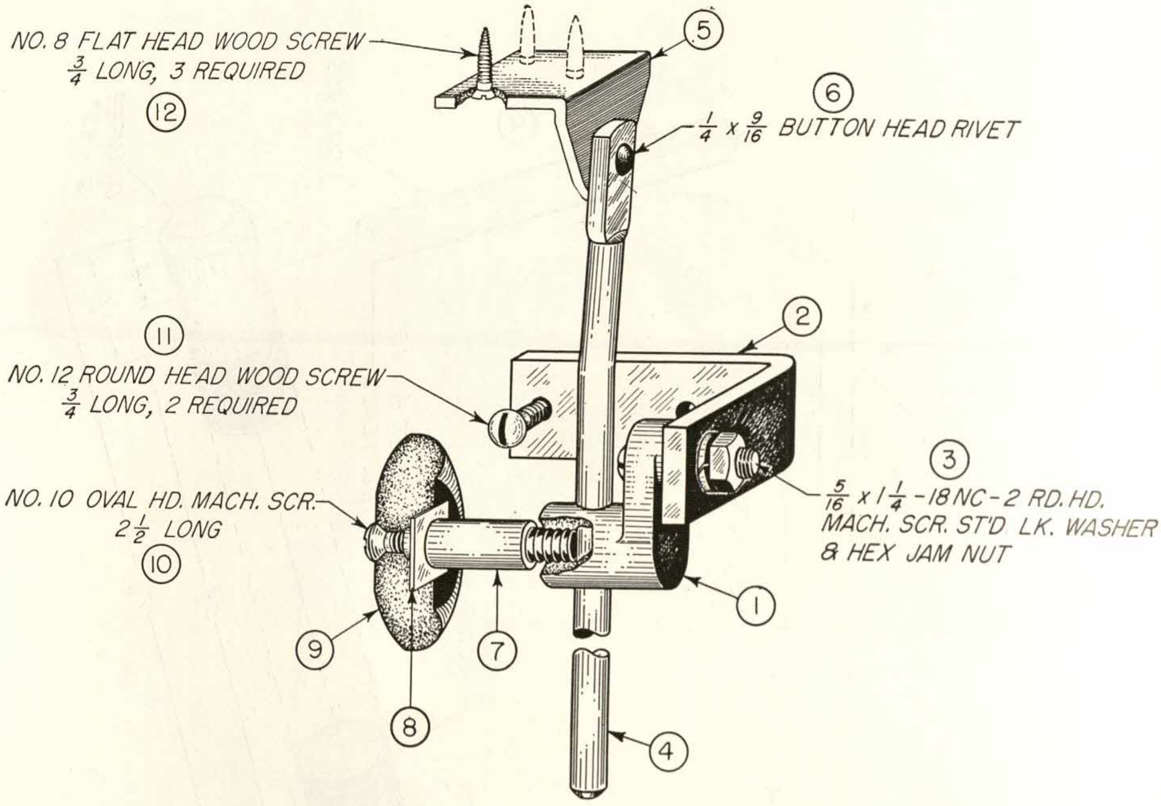
13-17. Make a two-view working assembly of the pipe support on an 8½- by 11-in. sheet. Show sectioning where helpful. The base (1), lower clamp (2), upper clamp (3), and the screws are made of brass. (Time. 6 hr.)

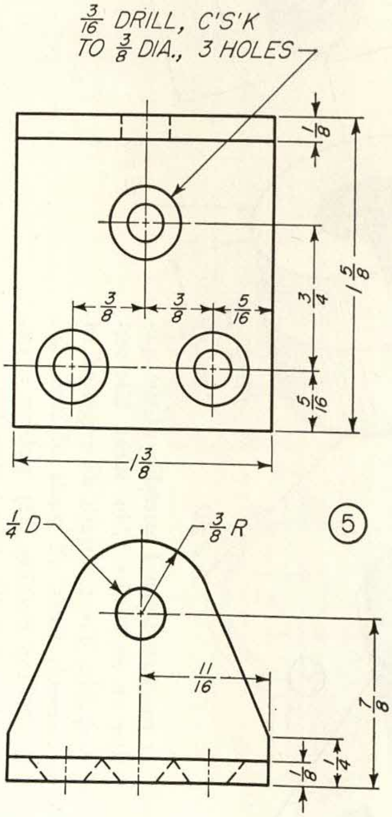


13-18. Make a two-view general assembly of the adjustable base on an 11- by 17-in. sheet. Employ standard sectioning procedure wherever you feel it will help make the drawing clearer. The assembly includes (1) cast-iron base, (2) cast-iron sliding adjuster, (8) cast-iron wing nut, and standard steel fasteners. Do not dimension the details. Show a title block and a bill of materials including all numbered parts. (Time. 8 hr.)

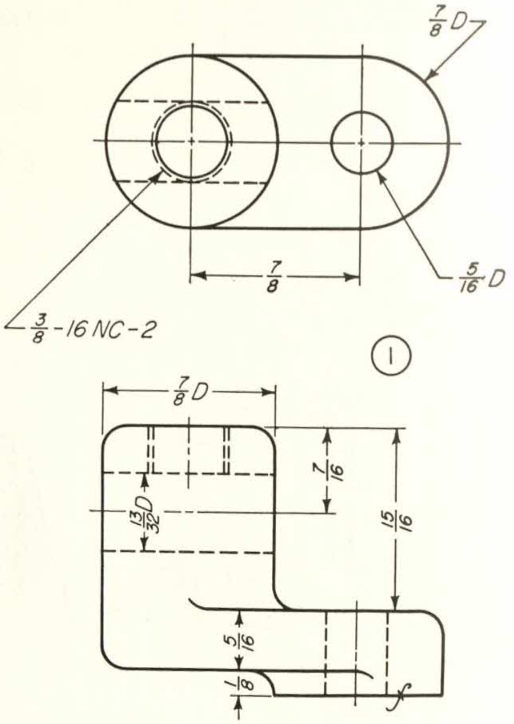


13-19. Make a two-view general assembly of the special bearing puller on an 11- by 17-in. sheet. Use sectioning where desirable. Treat threads as suggested in Chap. 12. The assembly parts, all made of steel, are (1) jaw holder, (2) top bushing, (3) pulling screw, (4) loose-pin handle, and (5) four adjustable jaws. Show only over-all dimensions. Include a complete title block and bill of materials on the drawing sheet. (Time. 7 hr.)

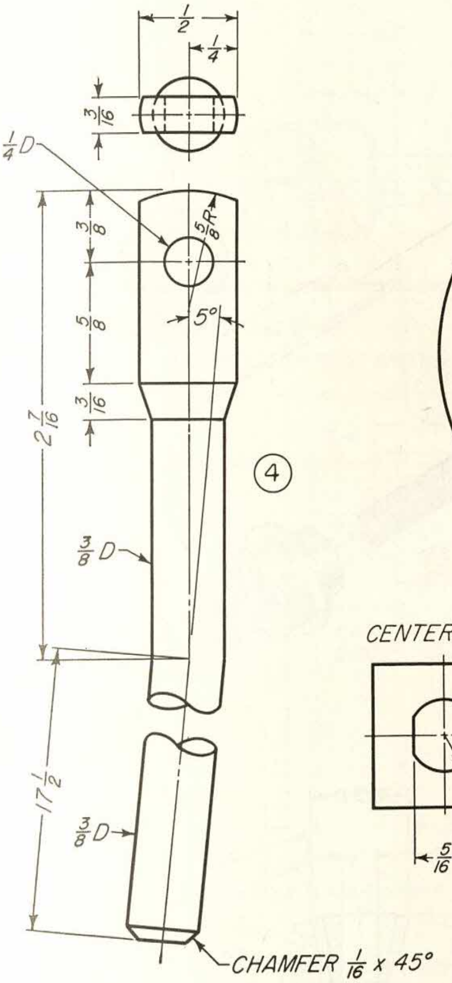

NO. 8 FLAT HEAD WOOD SCREW
3/4 LONG, 3 REQUIRED
⑫
⑤
⑥
1/4 x 9/16 BUTTON HEAD RIVET
②
⑪
NO. 12 ROUND HEAD WOOD SCREW
3/4 LONG, 2 REQUIRED
③
NO. 10 OVAL HD. MACH. SCR.
2 1/2 LONG
⑩
5/16 x 1 1/4 -18NC-2 RD. HD.
MACH. SCR. ST'D. LK. WASHER
& HEX JAM NUT
①
⑨
⑦
⑧
④



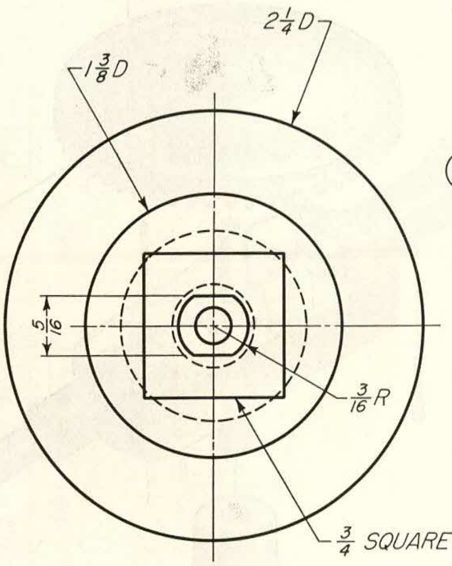
FILLETS & ROUNDS 1/8

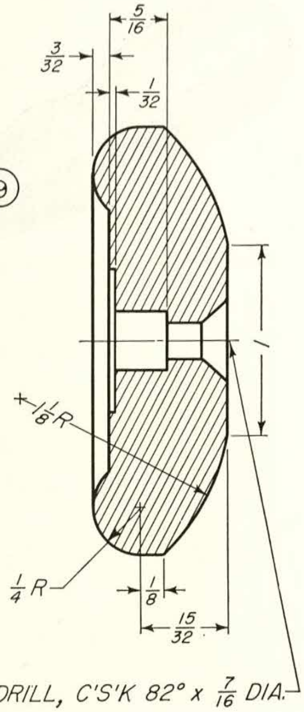


13-20. Make a two-view general assembly of the desk lift unit on an 11- by 17-in. sheet. Use sectioning where desirable. The 12-piece assembly consists of various standard steel fasteners identified by their specifications, and (1) cast-iron coupling, (2) steel base bracket, (4) steel extension rod, (5) steel desk-top bracket, (7) steel pressure shaft, (8) steel chip-prevention insert, and (9) a wooden handle. Do not dimension. Show a title block with a bill of materials on the drawing sheet. (Time. 12 hr.)

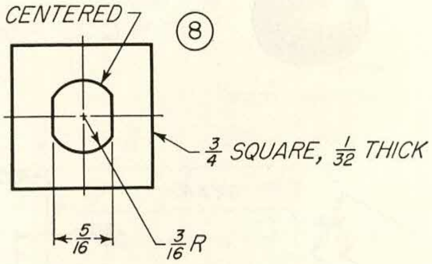

1/2
1/4
3/16
1/4 D
3/8
5/8 R
5/8
5°
3/16
2 7/16
3/8 D
17 1/2
3/8 D
CHAMFER 1/16 x 45°

④

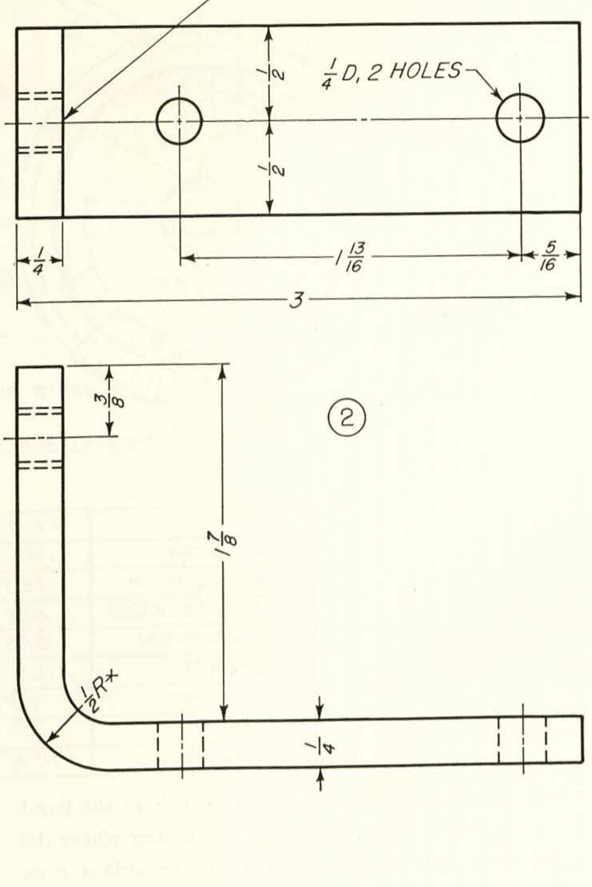

2 1/4 D
1 3/8 D
5/16
3/16 R
3/4 SQUARE


5/16
3/32
1/32
1
1 1/8 R
1/4 R
1/8
15/32
3/16 DRILL, C'S'K 82° x 7/16 DIA.

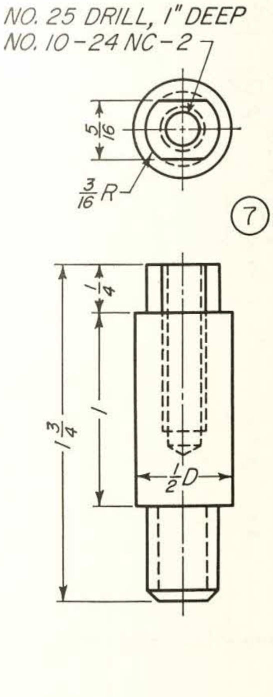
⑨


CENTERED
3/4 SQUARE, 1/32 THICK
5/16
3/16 R

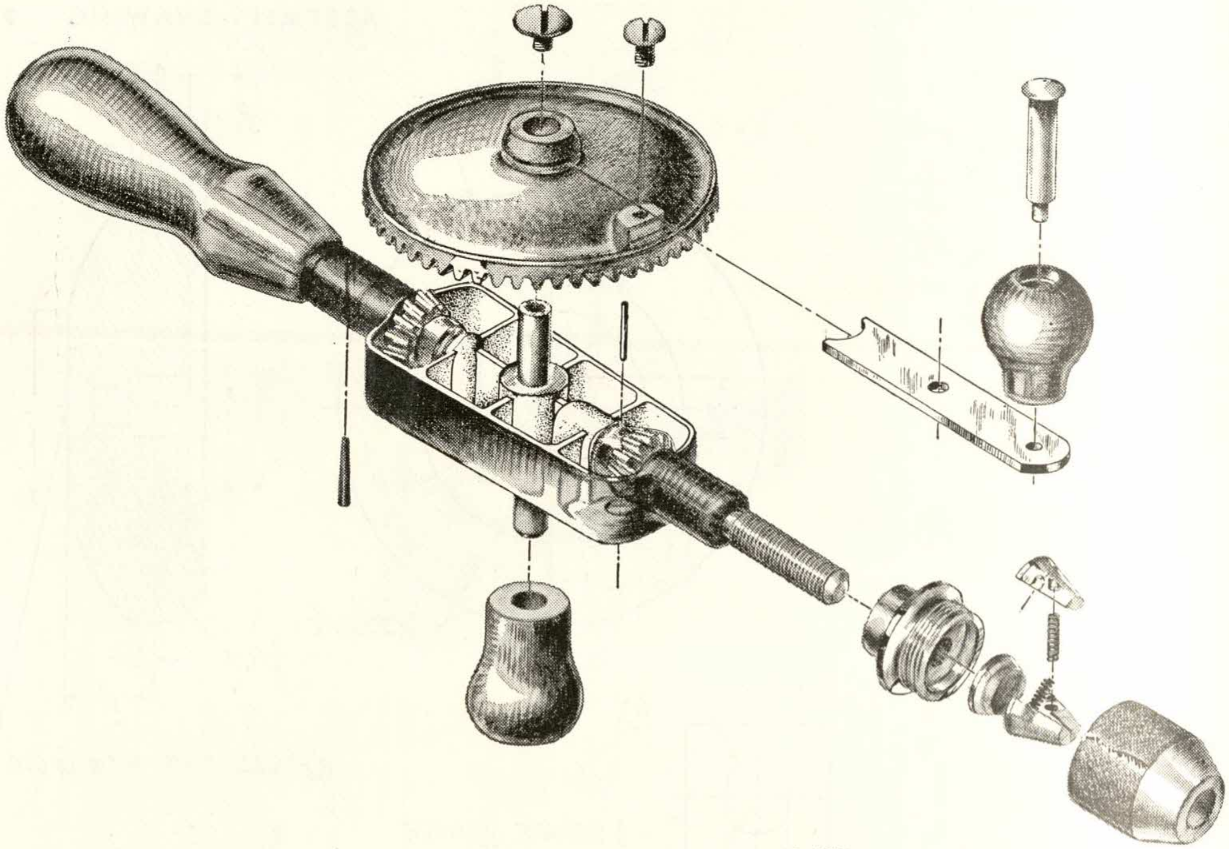
⑧

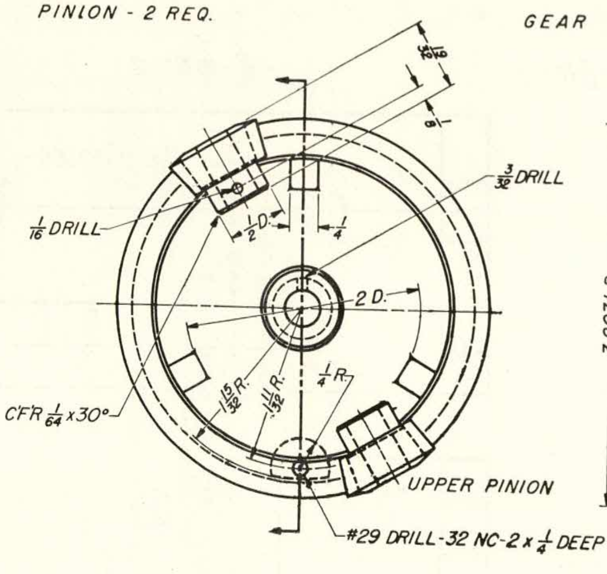

5/16-18 NC-2
1/4 D, 2 HOLES
1/2
1/2
1/4
1 13/16
5/16
3
3/8
1 7/8
1/2 R+
1/4

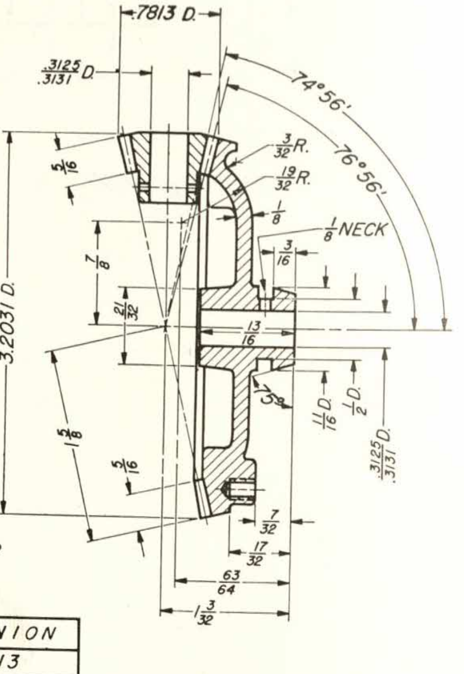
②


NO. 25 DRILL, 1" DEEP
NO. 10-24 NC-2
5/16
3/16 R
1/4
1
1 3/4
1/2 D

⑦



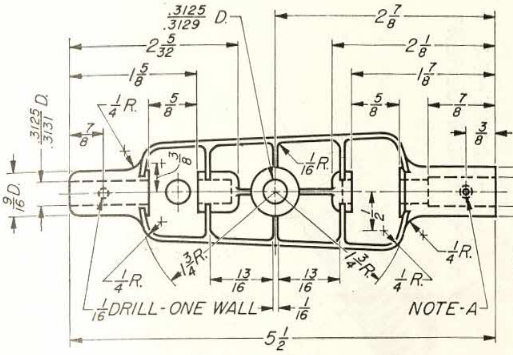

PINION - 2 REQ.


GEAR

	GEAR	PINION
NO. OF TEETH	56	13
DIAMETRAL PITCH	18.1	19.2
CHORDAL THICKNESS	.086	.081
CORR. ADDENDUM	.056	.054
WHOLE DEPTH	.119	.112
TOOTH FORM	20° STRAIGHT INV.	
CUTTER NO.	1	8
CUTTING ANGLE	11° 4'	74°56'

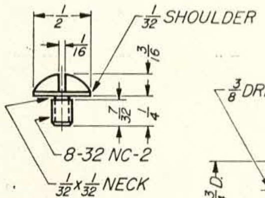
13-21. Make a two-view general assembly of the hand drill on an 11- by 17-in. sheet. Use sectioning where desirable. Show only over-all dimensions. Include a complete title block, bill of materials, and record strip. (Time. 22 hr.)

HOUSING (CAST IRON)

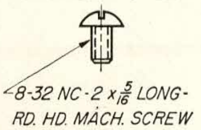


FILLETS & ROUNDS 1/8 UNLESS OTHERWISE SPECIFIED

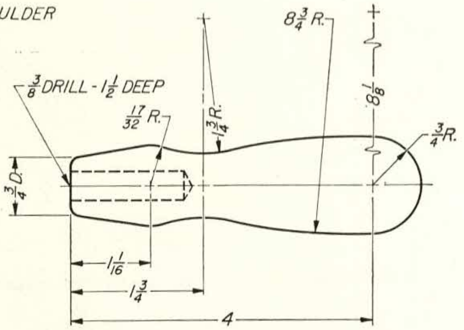
GEAR RETAINING SCREW



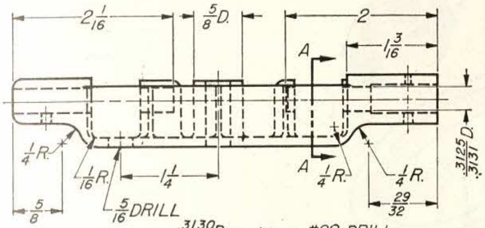
CRANK RET. SCREW

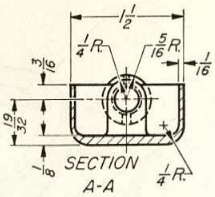


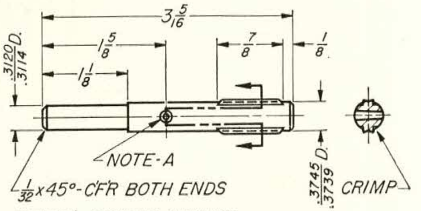
UPPER SUPPORT HANDLE



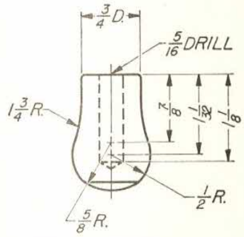
NOTE A: DRILL & REAM FOR #000 TAPER PIN IN ASSEMBLY

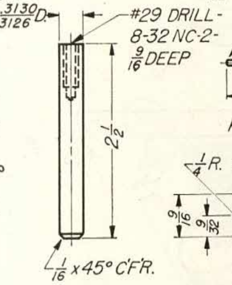


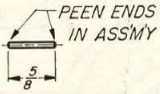




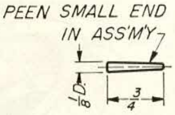
UPPER PINION SHAFT



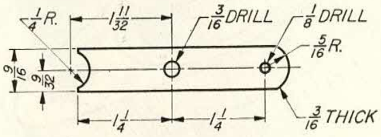




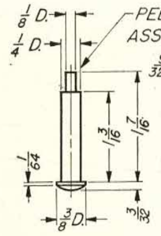
PIN

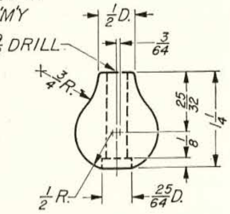


#000 TAPER PIN



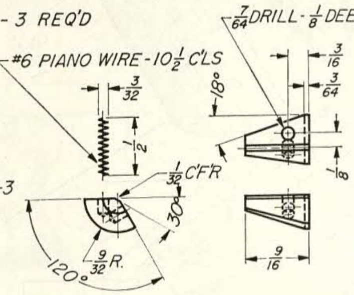
LATERAL SUPPORT KNOB GEAR & KNOB SHAFT CRANK

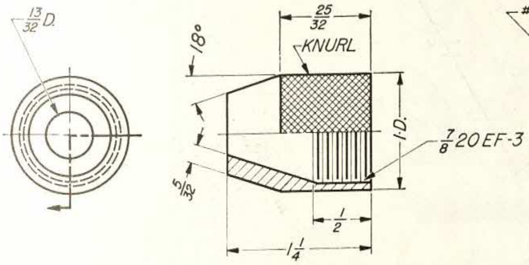


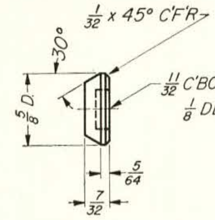


KNOB SHAFT CRANK KNOB

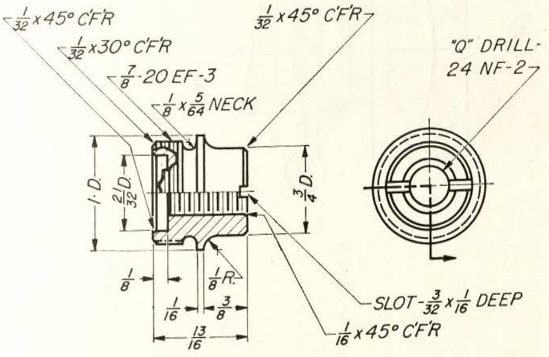
SPRING - 3 REQ'D

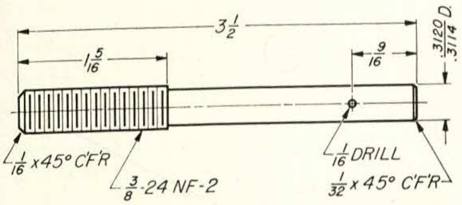




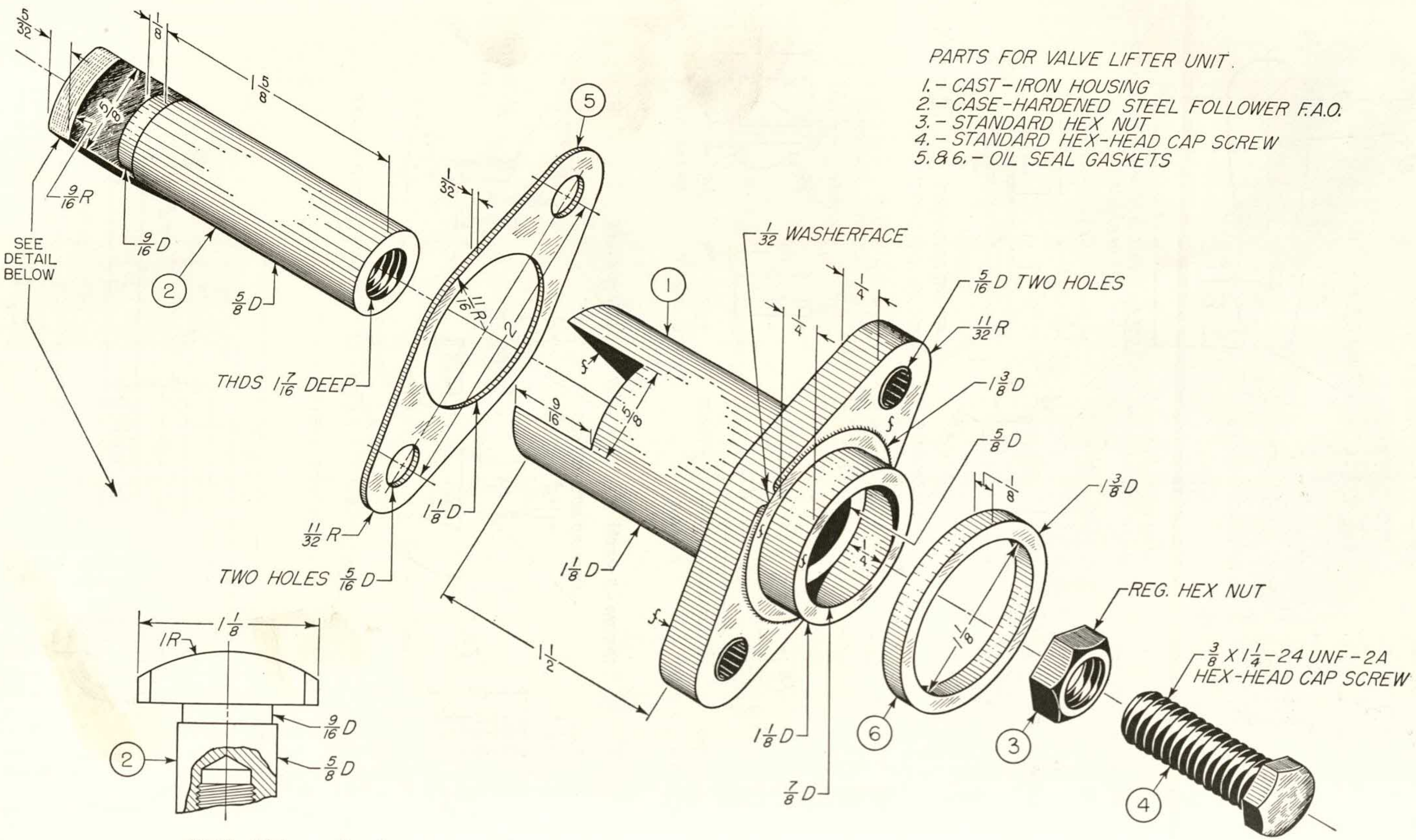


CHUCK CAP CHUCK JAW - 3 REQ'D COMPRESSOR PLATE



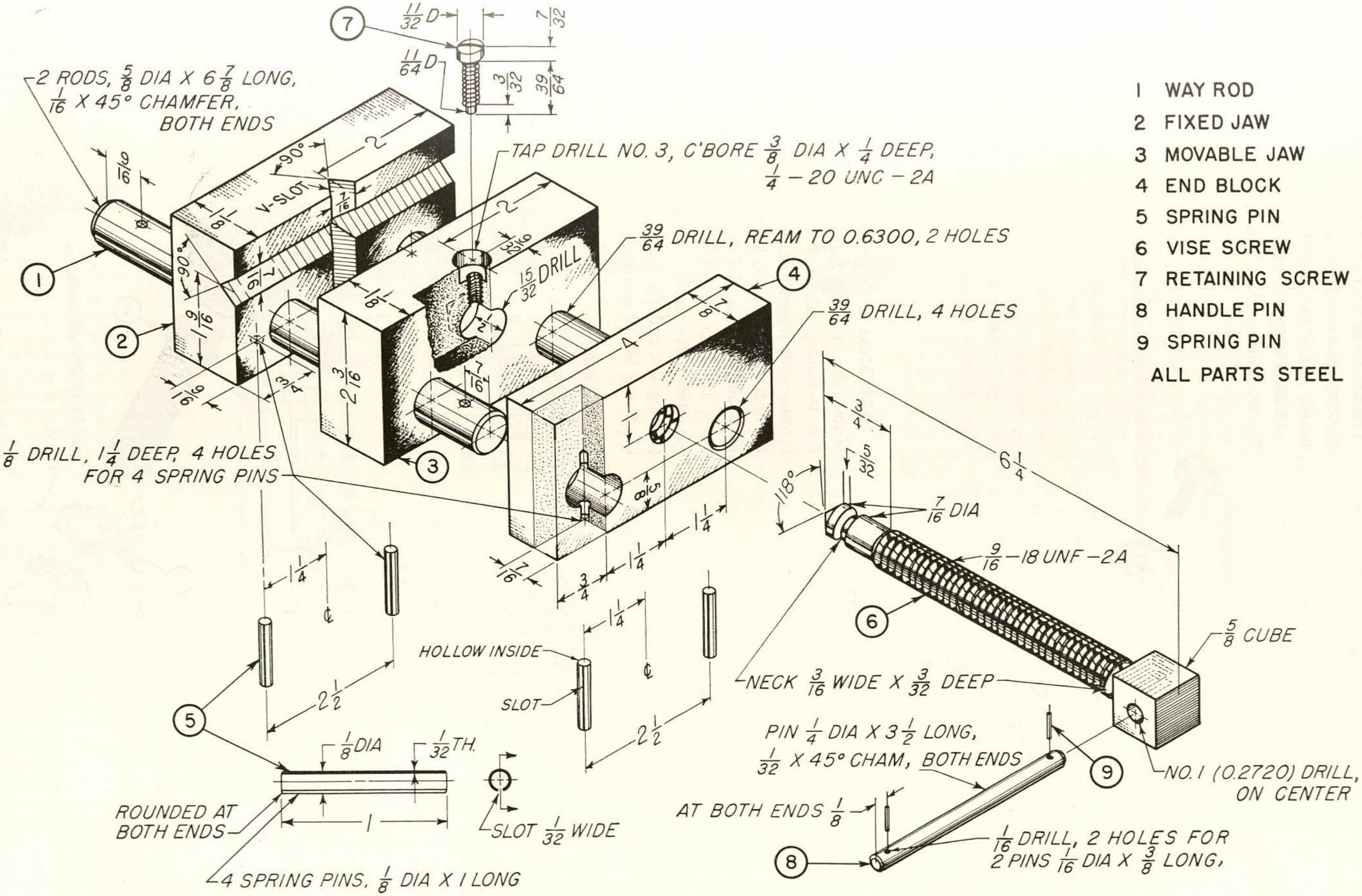


CHUCK RETAINING RING LOWER PINION SHAFT



13-22. Make a drawing showing the details of the valve-lifter unit completely dimensioned on an 11- by 17-in. sheet. (Time. 10 hr.)

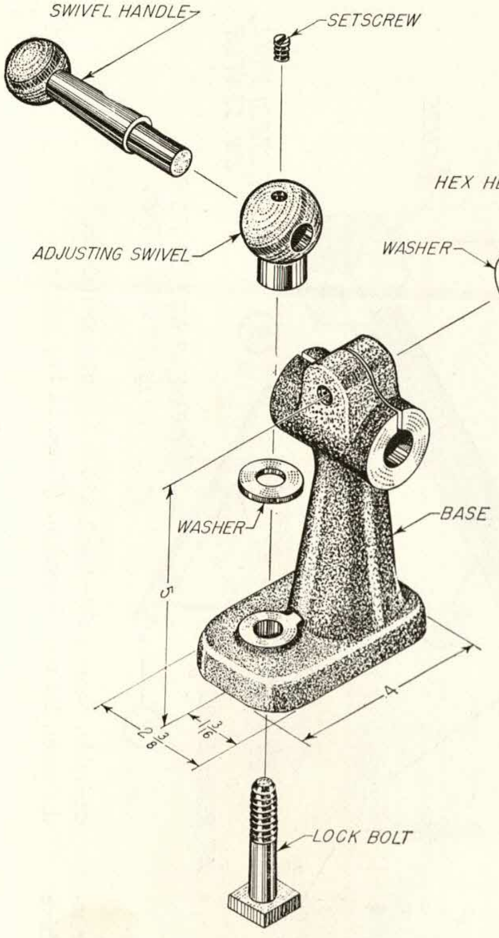
13-23. Make a two-view working assembly of the valve-lifter unit at double size on an 11- by 17-in. sheet. The housing and the gaskets may be shown in full or half section. A broken-out section will show the mating of the screw and the follower. A partial view of the follower is shown at the lower left in the illustration. Dimension all details, and include a title block and a bill of materials. (Time. 10 hr.)



2 RODS, 5/8 DIA X 6 7/8 LONG, 1/16 X 45° CHAMFER, BOTH ENDS
9/16
1
2
90°
V-SLOT
1 1/8
7/16
1 9/16
9/16
2
3/4
7
11/32 D
11/64 D
7/32
3/32
39/64
TAP DRILL NO. 3, C'BORE 3/8 DIA X 1/4 DEEP, 1/4 – 20 UNC – 2A
9/32
15/32 DRILL
1/2
1 1/8
2 3/16
7/16
3
39/64 DRILL, REAM TO 0.6300, 2 HOLES
4
7/8
39/64 DRILL, 4 HOLES
5/8
1 1/4
7/16
3/4
1/8 DRILL, 1 1/4 DEEP, 4 HOLES FOR 4 SPRING PINS
1 1/4
2 1/2
HOLLOW INSIDE
SLOT
5
1/8 DIA
1/32 TH.
ROUNDED AT BOTH ENDS
SLOT 1/32 WIDE
4 SPRING PINS, 1/8 DIA X 1 LONG
3/4
5/32
6 1/4
118°
7/16 DIA
9/16 – 18 UNF – 2A
6
5/8 CUBE
NECK 3/16 WIDE X 3/32 DEEP
PIN 1/4 DIA X 3 1/2 LONG, 1/32 X 45° CHAM, BOTH ENDS
9
NO. 1 (0.2720) DRILL, ON CENTER
AT BOTH ENDS 1/8
1/16 DRILL, 2 HOLES FOR 2 PINS 1/16 DIA X 3/8 LONG,
8

1 WAY ROD
2 FIXED JAW
3 MOVABLE JAW
4 END BLOCK
5 SPRING PIN
6 VISE SCREW
7 RETAINING SCREW
8 HANDLE PIN
9 SPRING PIN
ALL PARTS STEEL

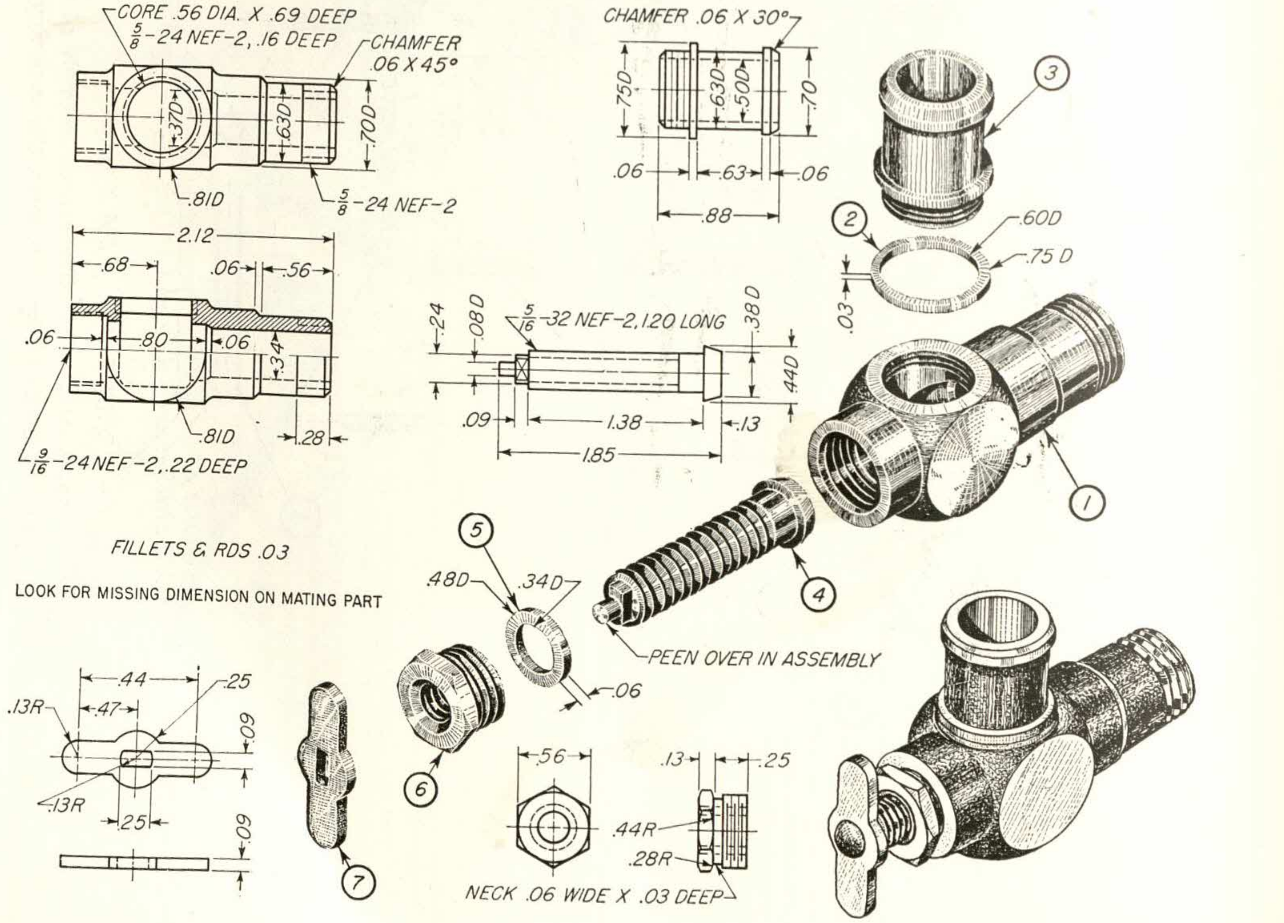
13-24. Make a two-view general assembly of the table vise on an 11- by 17-in. sheet. Use sectioning where desirable. Show a title block with a bill of materials on the sheet. Do not dimension. (Time. 12 hr.)



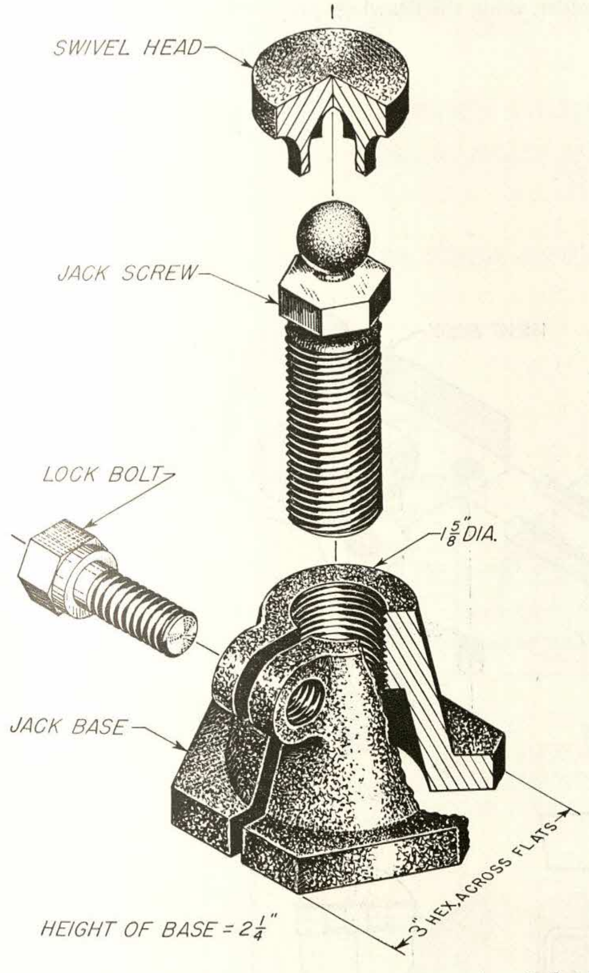
13-25. Make a set of working drawings of each of the standard parts and the other pieces required in an assembly of the tool holder.

13-26. Using the working drawings of the parts for the tool holder, make a unit general assembly drawing.

13-27. Make a single-view general-assembly drawing of the valve at a scale 1½″ = 1″ on an 8½- by 11-in. sheet. Use sectioning where desirable. Show threads in conformity with suggestions to be found in Chap. 12. Give the over-all dimensions for the completed assembly. The parts and the material they are made of are (1) brass body, (2) fiber sealing ring, (3) brass hose connector, (4) steel valve stem, (5) fiber sealing ring, (6) brass packing nut, and (7) steel tightening key. Include a title block and bill of materials.

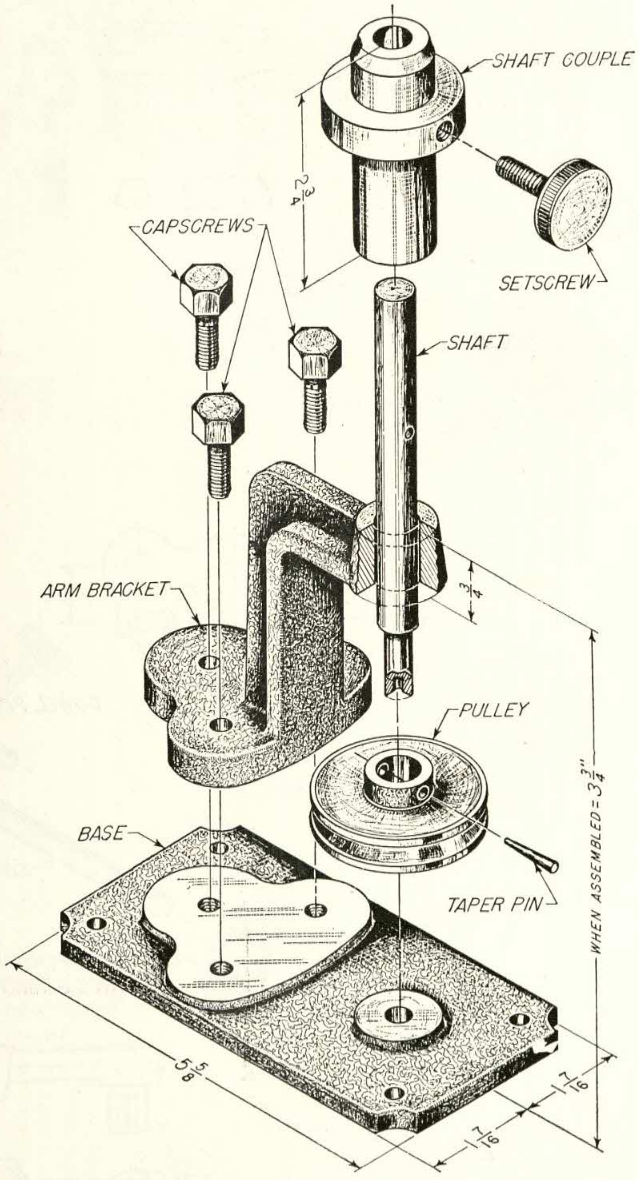


The following problems have been included at the request of instructors who wish to give more advanced students some experience and training in design work. Properly designed and carefully dimensioned full-size freehand drawings of each part should be made on rectangular-coordinate (grid) paper and checked and approved by the instructor before work is started on the final sheets. Where several of the completely dimensioned pieces are detailed on a single sheet, an individual simple title block, giving the name, scale, material, and number of pieces required, should accompany each representation. The assembly drawings should contain a title block and a complete bill of materials. Although strict adherence to what may be considered unimportant shapes or contours of the parts as illustrated is not necessary if the basic concept of the design of the entire unit as a functioning machine is successful, several dimensions on each drawing have been given to control the approximate size of the final product. Since the illustrations are shaded isometric drawings, some scaling of the parts may be resorted to if the principles of isometric drawing and dimensioning have been studied and are to be kept in mind when scaling other dimensions in proportion to the ones given.



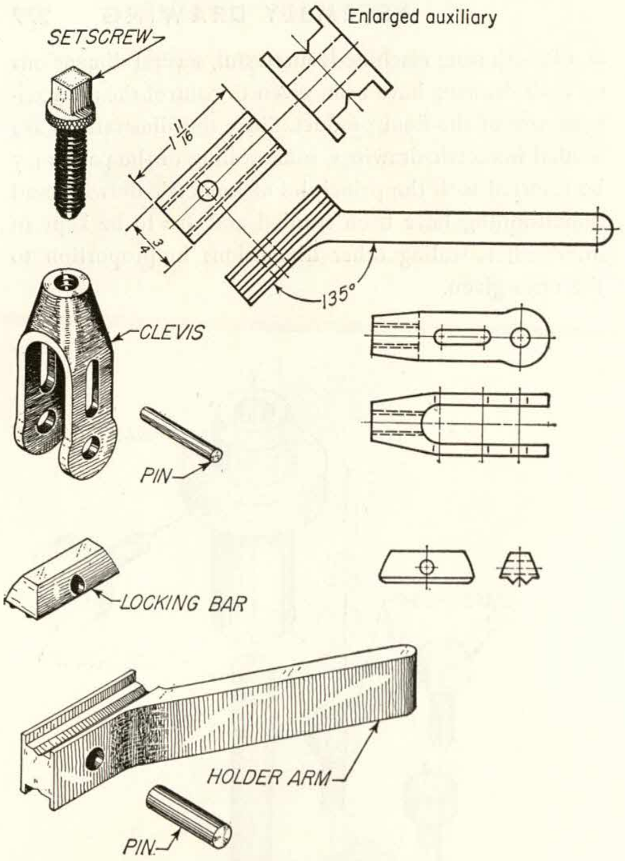
13-28. Make a set of completely dimensioned detail drawings showing your design of the pieces and your selection of any standard parts required for the machine jack. The swivel head is peened over on the jack screw in assembly.

13-29. From the details prepared for Prob. 13-28, make a working-drawing assembly of the machine jack.



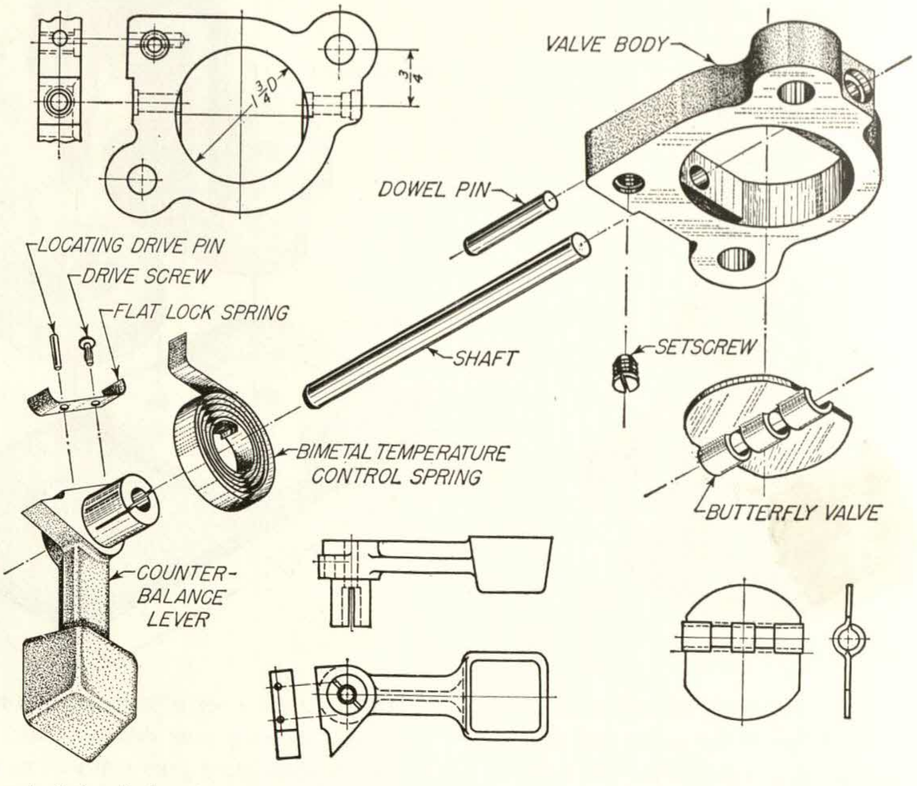
13-30. Make a set of completely dimensioned detail drawings showing your design of the pieces and your selection of standard parts you wish to use in producing a pulley-bracket unit very similar to the one shown in the figure.

13-31. Make a general assembly drawing of the pulley-bracket unit, using the parts designed and selected in working Prob. 13-30.



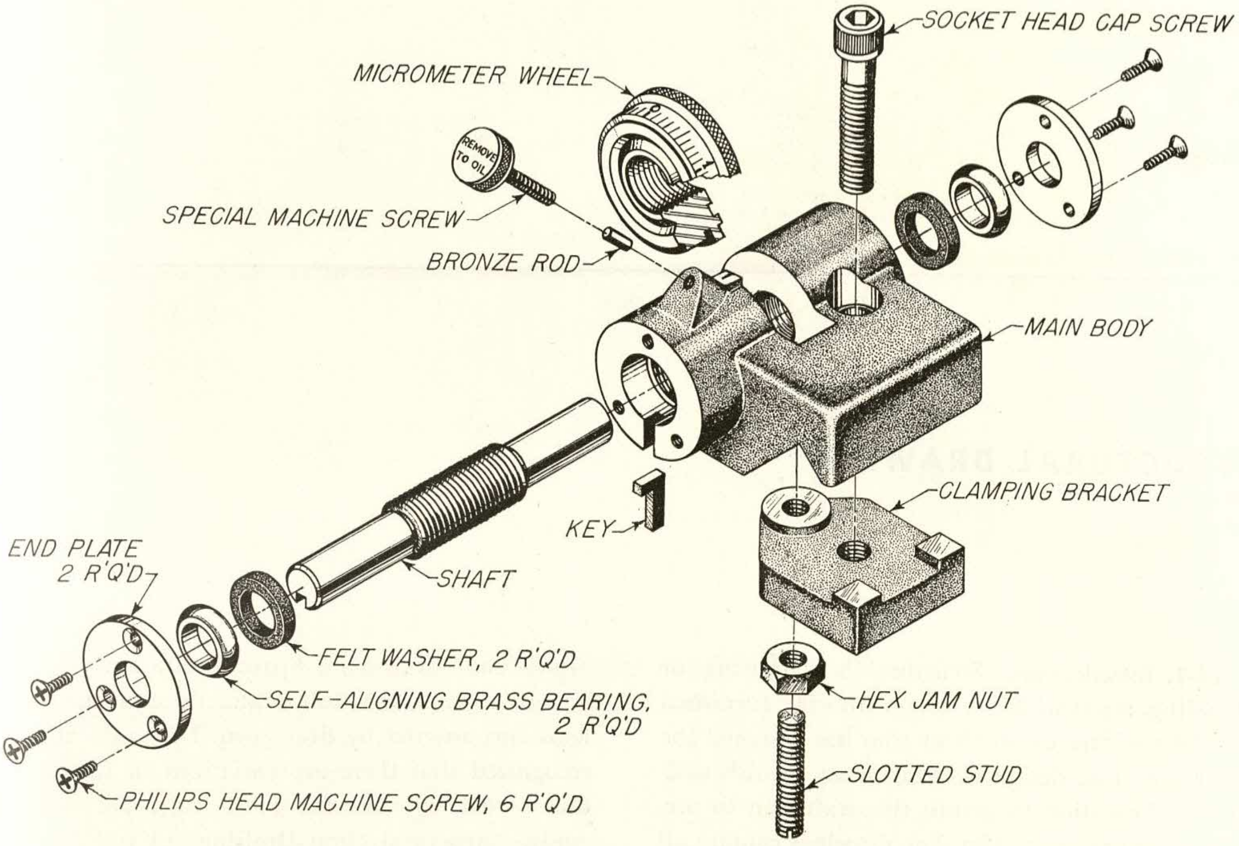
13-32. Make a set of detail drawings of the parts for the tool holder. The orthographics of three of the pieces and several controlling dimensions are shown for your convenience.

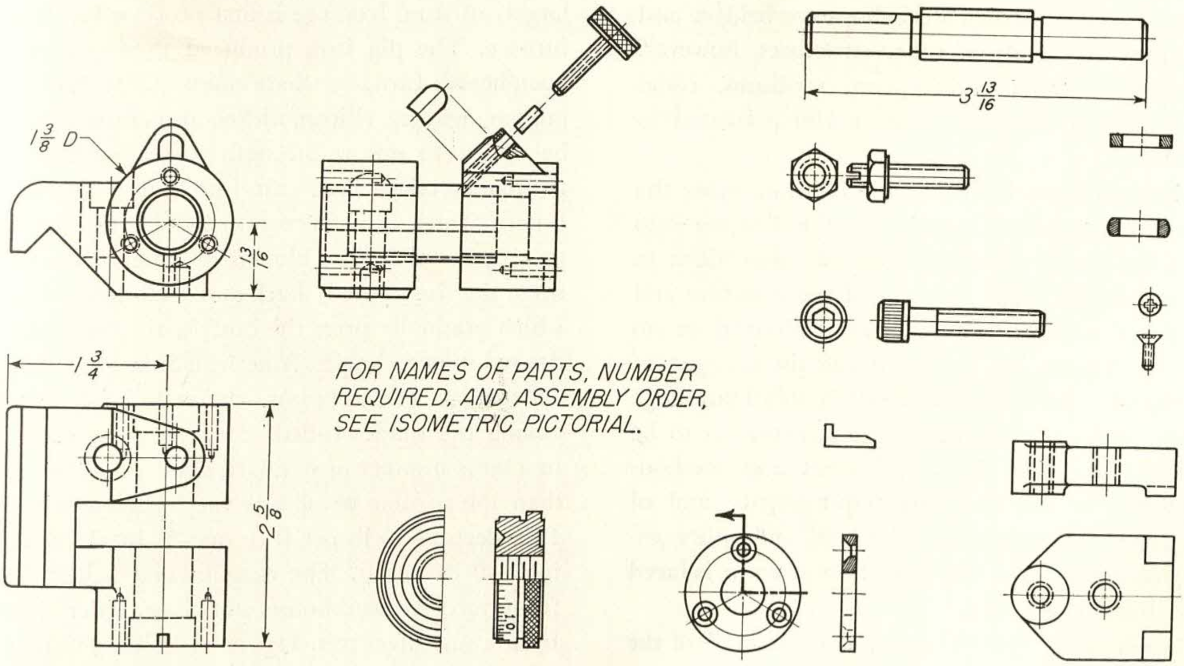
13-33. Make a working assembly drawing of the tool holder, using the drawings prepared for Prob. 13-32.



13-34. Make a set of detail drawings of the parts for the heat riser. The orthographics of three of the parts and several controlling dimensions are shown for your convenience.

13-35. Make a general assembly drawing of the heat riser, using the drawings prepared for Prob. 13-34.





FOR NAMES OF PARTS, NUMBER REQUIRED, AND ASSEMBLY ORDER, SEE ISOMETRIC PICTORIAL.

13-36. Make a set of detail drawings of the parts for the micrometer stop. The orthographics of most of the parts and several controlling dimensions are shown for your convenience.

13-37. Make a general assembly drawing of the micrometer stop, using the drawings prepared for Prob. 13-36.

Chapter 14

STRUCTURAL DRAWING*

14-1. Introduction. Structural-shop drafting, or detailing, starts with the design drawing furnished by the engineer or architect who has designed the structure. The design drawing must furnish sufficient information to permit the draftsman to prepare shop drawings. The shop drawings contain all the information needed to fabricate, to prepare for shipping, and to erect the structure. The usual structures fabricated in steel shops are bridges and buildings. A variety of other structures, however, including railroad freight cars, stadiums, canal locks, and mining equipment is also produced in steel shops.

The draftsman is responsible for translating the general information supplied by the designer into drawings giving complete detailed instructions to be used in the shop. The cost of the structure and the speed and ease of fabrication depend in no small part upon the judgment and the accuracy of the detailer. He must have a satisfactory knowledge of the material with which the structure is to be fabricated, of the shop equipment and methods employed, of the shipping requirements, and of the erection procedures. Checkers and other experienced personnel will assist him when he is faced with difficult decisions.

Copies of the "Steel Construction Manual" of the American Institute of Steel Construction (AISC) and of Smoley's "Tables of Logarithms and Squares" and "Slopes and Rises" are essential to the professional draftsman. Space limitations in this type of book prevent full treatment of all the problems encountered by draftsmen. It should also be recognized that there are variations in the procedures used by different fabricators. For further study, "Structural Shop Drafting" of the AISC is recommended.

14-2. Plain material. Structural steel consists largely of iron. Iron ore is first processed in a blast furnace. The pig iron produced then goes to an open-hearth furnace, where small quantities of carbon, manganese, silicon, nickel, and chromium may be added to ensure strength and ductility. The molten metal is then cast into slabs, blooms, or billets. Plates and structural shapes are formed by passing the slabs (or blooms or billets, depending upon the size needed) back and forth between rolls which gradually press the hot plastic steel into the desired shapes. Angles, American Standard I beams, wide-flange (WF) beams, channels, and zees are among the shapes rolled. Each shape is produced in a large number of standard sizes. There are more than 150 regular WF shapes varying from a section 4 in. deep of 13 lb per ft to one 36 in. deep weighing 300 lb per ft. The detailer may select shapes from yard or warehouse stocks or order directly from a manufacturer. Figure 14-1 shows how plain material is described, or "billed."

14-3. Fabrication. Before fabrication is started, drawings must go to the template shop. Here wood

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* This chapter was written by Professor Thomas Brockenbrough.

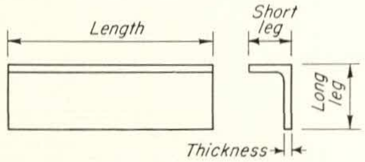
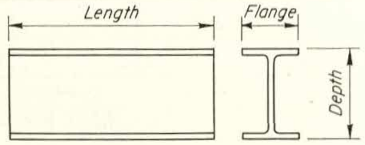
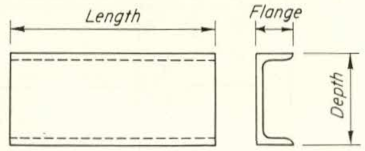
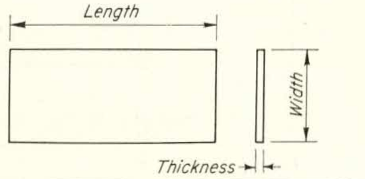
Shape	Billing example	Identification of dimensions
Angles	L 5 x $3\frac{1}{2}$ x $\frac{5}{8}$ x 6'-3 Shape symbol | Long leg | Short leg | Thickness | Length	
American std. I-beams Wide flange beams	14 WF 53 x 21'-$6\frac{1}{4}$ Depth | Shape symbol | Wt (lbs/ft) | Length	
American std. channels	15 [50.0 x 12'-$4\frac{1}{2}$ Depth | Shape symbol | Wt. (lbs/ft) | Length	
Plates	P $48\frac{1}{2}$ x $\frac{7}{16}$ x 12'-6 Shape symbol | Width | Thickness | Length	

Fig. 14-1. Billing of plain material.

or cardboard templates are made of the gusset plates and of other items. Large components are often "measured out" in the shop without the use of patterns.

The principal shop operations include sawing, shearing, and burning parts to prescribed lengths; punching and drilling holes for connections; riveting, bolting, or welding parts together; and finally cleaning, painting, and preparing assembled units and loose parts for shipment. Knowledge of the shop equipment involved and a good understanding of its use are obviously needed by the draftsman so that his plans can be efficiently executed. Drawings for simple structures may be prepared by the inexperienced detailer; after experience has been acquired, more difficult structures can be attempted.

14-4. Building frames. The usual office building is several stories high. Every floor and the roof are supported by beams framed between girders, which in turn are supported by columns. The interior and exterior walls are usually supported at each floor level by the steel frame. The draftsman must supply a foundation or anchor-bolt plan (see Fig. 14-2), an erection plan (see Fig. 14-3), and

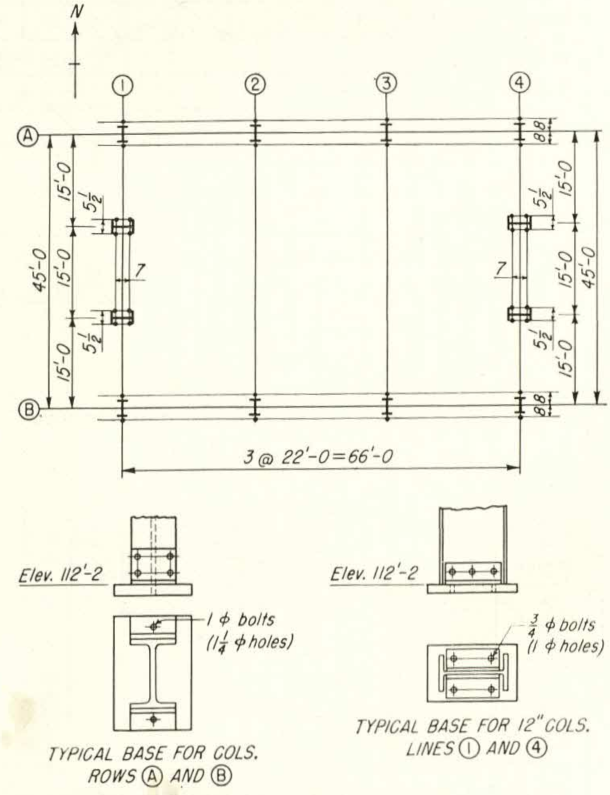

N
①
②
③
④
Ⓐ
Ⓑ
15'-0
$5\frac{1}{2}$
7
45'-0
8
3 @ 22'-0=66'-0
Elev. 112'-2
Elev. 112'-2
1 ϕ bolts ($1\frac{1}{4}$ ϕ holes)
$\frac{3}{4}$ ϕ bolts (1 ϕ holes)
TYPICAL BASE FOR COLS. ROWS Ⓐ AND Ⓑ
TYPICAL BASE FOR 12" COLS. LINES ① AND ④

Fig. 14-2. An anchor-bolt plan.

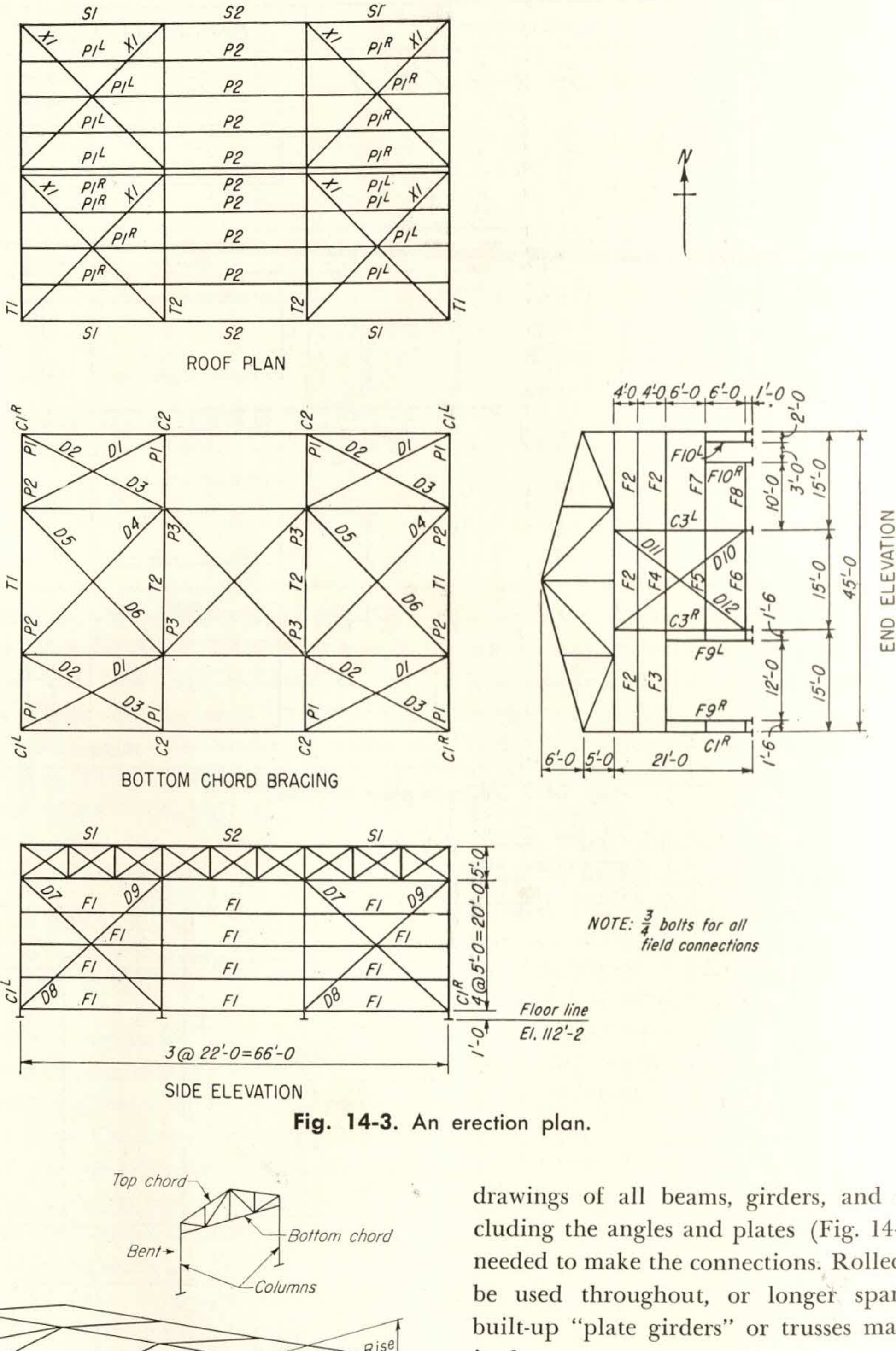


Fig. 14-3. An erection plan.

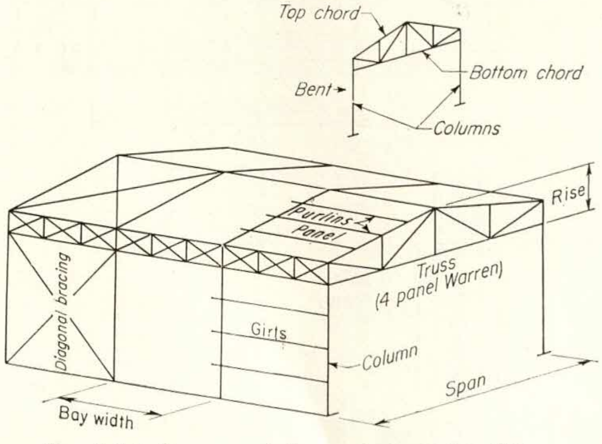


Fig. 14-4. Framework for an industrial building.

drawings of all beams, girders, and columns, including the angles and plates (Fig. 14-18) that are needed to make the connections. Rolled shapes may be used throughout, or longer spans requiring built-up "plate girders" or trusses may be needed in the structure.

Many industrial buildings are only one story in height. These structures consist of several bents framed together with suitable bracing to form the building. The bents are composed of trusses supported by columns. Roof beams, called "purlins," and wall beams, known as "girts," extend between the bents. (See Fig. 14-4.)

Diameter		1/2	5/8	3/4	7/8	1	1 1/8	1 1/4
Strength (lbs)	Rivets	2,950	4,600	6,630	9,020	11,780	14,910	18,410
	Bolts	1,960	3,070	4,420	6,010	7,850	9,940	12,270

Fig. 14-5. Shear strength of rivets and bolts.

14-5. Connections: riveting and welding. Nearly all beam, column, and truss members are composed of either a single or a pair of rolled shapes. Therefore, detailing (drawing and dimensioning) is concerned almost entirely with connections. The several examples given with the accompanying discussion illustrate typical connections. The general problems of strength and designation of rivets and welds will be considered here.

To avoid confusing shopmen, a strong effort should be made by the detailer to use the same size rivet or bolt throughout a structure. For the same reason, it is also desirable to avoid excessive use of different kinds and sizes of weld. For light building work and short-span roof trusses ¾-in.-diameter rivets are adequate. Heavier building frames and bridge work require 1-in.-diameter rivets. For unusually heavy construction, 1⅛- or 1¼-in.-diameter rivets may be needed. The use of ½- or ⅝-in.-diameter rivets is confined to transmission towers, bracing, signs, etc. The number of rivets or the amount of welding (fillet and butt welds predominate in steel construction work; see Secs. 12-32 to 12-36) required for a connection depends upon the load to be carried. Design drawings usually specify the loads; otherwise, minimum standards prevail. Standard connections for all beam sizes are diagrammed and tabulated in the "Steel Construction Manual" of the AISC.

Rivet holes are ordinarily $\frac{1}{16}$ in. larger in diameter than the rivets. Punched holes may be somewhat ragged. "Truer" holes can be obtained by drilling or punching them undersize and then reaming. Holes in thick plates and flanges must be drilled. Sufficient space for riveting must be provided when locating rivets in a member. Adequate spacing and edge distance (center of the rivet to the adjacent edge of the part) is necessary. The single-shear strength of rivets and bolts is tabulated in Fig. 14-5. When rivets (or bolts) are symmetrically loaded, the strength of two cross sections is developed and they are capable of withstanding twice the single-shear strength. If the attached parts are too thin, they may not utilize the capacity of the rivets. See also Secs. 12-30 and 12-31.

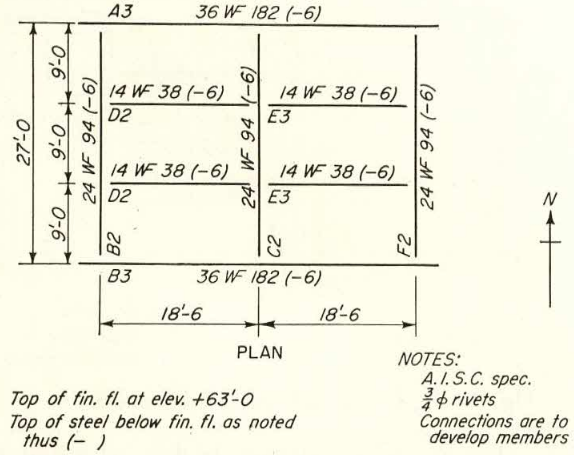


Fig. 14-6. Design plan of beams and girders.

14-6. Square-framed beams, standard connections. Figure 14-6 shows a portion of a plan from a design drawing. It includes all the information about the beams given to the detailer by the designer. Notice that the elevation of the top of the finished floor is given. The elevation of the tops of the beams and girders with respect to the finished floor appears in parentheses alongside the specification of each beam. Each beam is identified by a letter and a number placed near it.

The first step in detailing the two beams shown in Fig. 14-7*a* is to select standard connections strong enough to develop the strength of the beams. The AISC "Manual" is consulted, and the capacity of a 14 WF 38 shape on an 18 ft 6-in. span is listed as 39 kips (1 kip = 1,000 lb). The tables show that the lightest standard connection, B3, is adequate. The B3 connection is shown in the manual to be made up of 2 ∠ 4 × 3½ × ⅜ × 8½ fastened to the beam by three ¾-in.-diameter rivets. Long-established usage by fabricators requires the following:

1. The web leg must be 3½-in. with a 2½-in. gage. (See Fig. 14-7*b* for usual gages.)

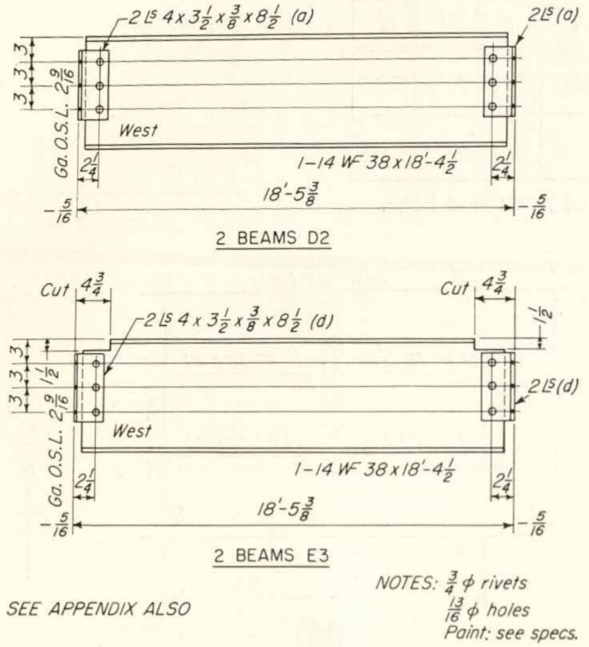


Fig. 14-7a. Beams with standard connections.

2. The outstanding leg must be 4 in. with a gage that will make the spread, or distance between gage lines, in the outstanding legs $5\frac{1}{2}$ in. In this instance, g (gage) $= \frac{1}{2}\,(5\frac{1}{2} - \frac{3}{8}) = 2\frac{9}{16}$.

3. The pitch, or spacing, of rivets must be 3 in. (center to center).

4. For standardization when practicable, the first rivet must be 3 in. below the top of the beam.

5. The end distances on the angle must each be equal to one-half of the difference between the length of the angles and the distance between the outside rivets.

For dimensioning purposes, the manual shows the *"c* distance" from the center of the supporting member to the face of the angles. This will be one-half of the web thickness of the supporting member plus $\frac{1}{16}$ in. In Fig. 14-7*a*, the two $\frac{5}{16}$ in.'s are subtracted from the 18-ft 6-in. span, leaving 18 ft $5\frac{3}{8}$ in. The length of the beam is billed $\frac{3}{8}$ in. to $\frac{1}{2}$ in. less so that, after cutting at the mill, no additional cutting or fitting is required. The two angles at the ends of the beam are billed once and given the symbol *a*. If similar ones can be used elsewhere, they will be identified by the symbol given to these angles, and additional detailing will not be necessary.

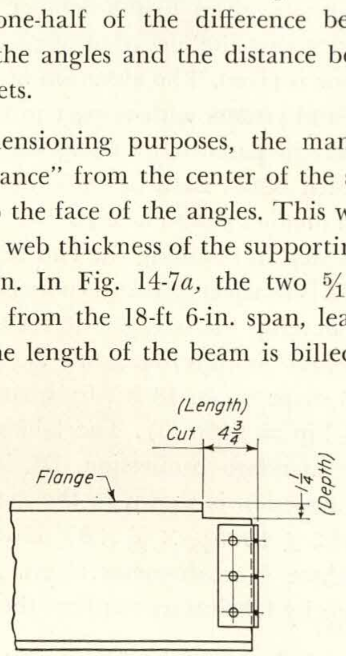


Fig. 14-8. Dimensioning a cope.

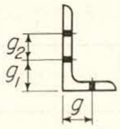
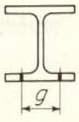
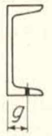
Shape	Gauge							
	Leg	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4	5	6
	g	$1\frac{1}{8}$	$1\frac{3}{8}$	$1\frac{3}{4}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
	g_1						2	$2\frac{1}{4}$
	g_2						$1\frac{3}{4}$	$2\frac{1}{2}$
	Flange	4	5 to $5\frac{1}{4}$	6 to $7\frac{1}{2}$	8 to $16\frac{5}{8}$			
	g	$2\frac{1}{4}$	$2\frac{3}{4}$	$3\frac{1}{2}$	$5\frac{1}{2}$			
	Flange	$2\frac{1}{8}$ to $2\frac{1}{4}$	$2\frac{1}{4}$ to $2\frac{1}{2}$	$2\frac{5}{8}$ to $2\frac{3}{4}$	$2\frac{7}{8}$ to $3\frac{1}{8}$	$3\frac{3}{8}$ to $3\frac{1}{2}$	$3\frac{3}{4}$	4 to $4\frac{1}{4}$
	g	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2	$2\frac{1}{4}$	$2\frac{1}{2}$

Fig. 14-7b. Usual gages for rolled shapes.

Portions of flanges must sometimes be cut away to avoid interferences. This notching or cutting may be referred to as a "cope," "block," or "cut." The cope must be long enough to provide $\frac{1}{2}$-in. clearance between flanges and deep enough to remove completely the flange that is being coped (see Fig. 14-8).

14-7. Beams having seated connections. The use of seated beam connections reduces the number of field rivets required and saves erection time and costs. Over-all economy can be obtained (even with an increased number of parts and rivets) because shop riveting is more convenient and simpler than field riveting. Figure 14-9*a* shows two views of a beam-to-girder-seated connection. The beam is supported entirely by the seat angle beneath it. The angle attached to the web provides stability against overturning and assists in properly positioning the beam. Both angles are attached to the larger girder in the shop. Figure 14-9*b* shows the use of a top angle instead of one attached to the web of the beam. The purpose of this angle is to provide stability, although in this position the angle functions somewhat as wind bracing. The beam load to be supported and the thickness of the beam web determine the thickness of the seat angle. When the beam reaction exceeds 35 kips, the seat angle must be strengthened by one or two stiffeners, as shown in Fig. 14-9*c*. (See pictorial of seated connections, Fig. 13-7.) The seat angles and stiffeners required for an extensive range of loads are tabulated in the "Steel Construction Manual."

Little detailing is required for a beam having seated connections. Figure 14-10 shows the plan of a beam taken from a design drawing. Figure 14-11 is a detail drawing of the beam. The centers of the columns are working points. The $7\frac{1}{2}$-in. dimension from working point to edge of beam includes half the depth of the columns plus $\frac{9}{16}$-in. end clearance; about $\frac{1}{2}$ in. would be ample for clearance, but $\frac{9}{16}$ in. is used to reduce the denominator of the fraction. The length of the beam is determined by subtracting the two $7\frac{1}{2}$-in. dimensions from the 15-ft 0-in. center-to-center distance of the columns. Note that $\pm\frac{1}{4}$ in. at each end, or a total of $\pm\frac{1}{2}$ in. between the detailed length and actual length, is permitted. The distance between end rivets is 13 ft 5 in. This must be held (maintained). The shop recognizes this, and will vary the pitch of the end rivets from the 2 in. shown as may be necessary.

The detailing of beams framed between the flanges of columns is done in a similar fashion. An exception would be the possible need of dimensioning the coping for clearance.

14-8. Columns. Columns are ordinarily spaced along the sides of industrial structures to support trusses. They may be arranged in a grid system to support beams and girders at each floor level of office buildings. Practically all steel columns are WF shapes. A 14 WF 426 section without cover plates will support as much as 2,000,000 lb. The framing of multistory buildings is commonly divided into tiers two stories high. All columns are spliced at the same level so that erection can proceed one tier at a time.

Splices are made by milling the ends of columns to flat plane surfaces so that the column above bears evenly against the one below. Side plates are riveted or welded to the flanges to hold the two sections together and prevent slipping. To facilitate splicing, nearly all WF sections of the same nominal depth have exactly the same dimension between the inside faces of the flanges. The flanges of the uppermost tier are thin; in lower tiers they are thicker to support greater loads. The bottom tier may have flanges as thick as 3 in.

All steel columns rest on bearing plates. The bearing plates are necessary to distribute the column load over a sufficient amount of concrete to avoid crushing. The size of bearing plate needed de-

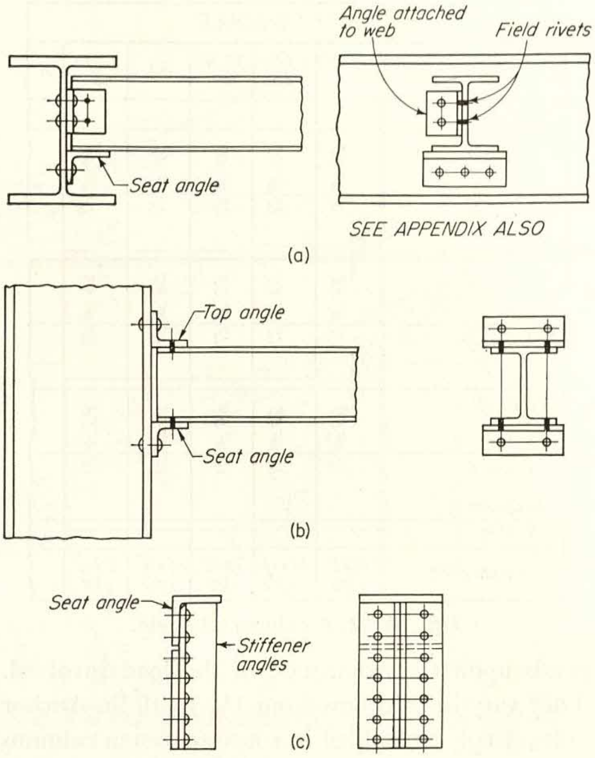
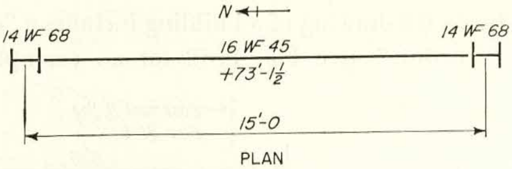


Fig. 14-9. Beam seats.



Elevation top of steel as shown
NOTE: Use A.I.S.C. specifications
Rivets ¾ φ; Holes $\frac{13}{16}$

Fig. 14-10. Design plan of beam framed between columns.

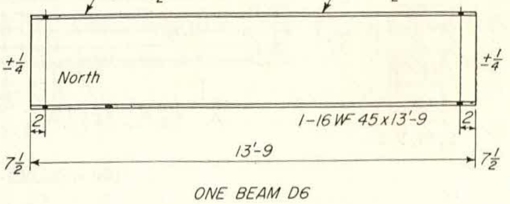


Fig. 14-11. Beam detailed for seated connection.

COLUMN SCHEDULE						
Floor / Column mark	A1 to A4	A5 A6	B2, B3 B4	B5	C2 to C5	C1
Roof						
El. 157'-1¾ Fifth	12 WF 40	12 WF 40	12 WF 40	12 WF 40	12 WF 40	
El. 147'-1¼ Fourth	2'-0				1'-6	
El. 136'-1½ Third	12 WF 53	12 WF 40	12 WF 53	12 WF 40	12 WF 53	
El. 124'-1½ Second	2'-0					
El. 112'-0 First	12 WF 58	12 WF 45	12 WF 58	12 WF 45	12 WF 58	
El. 100'-0 Basement fl.		1'-3				
El. 91'-6						
Col. base plate	18x2 x20	14x1½ x20	18x2 x20	14x1½ x20	20x2 x24	

Fig. 14-12. A column schedule.

pends upon the magnitude of the load involved. They vary in thickness from 1¼ to 10 in. Anchor bolts, deeply embedded in concrete, fasten columns down to prevent any tilting by heavy winds. (See Figs. 13-7 and 14-2.)

The design drawing of a building includes a "column schedule" (see Fig. 14-12 for an example), which specifies the rolled shapes to be used, the location of splices, and the size of base plates. Columns are detailed on the basis of the information shown on the column schedule and framing plans. Framing plans show the members that frame into the columns at each floor level.

The first members of a building erected are the columns. Therefore, they must be among the first to be detailed and sent to the shop for fabrication. The attachment of all floor beams and girders must be provided for in addition to the splices. Figure 14-13 is an example of how columns are detailed.

14-9. Roof trusses. The Fink, Pratt, Howe, Fan, and Warren are among several types of commonly used roof trusses. The span and the pitch (ratio of rise to span) may vary. The truss may be divided into four, six, or eight similar units, known as "panels" (see Fig. 14-4). Monitors, skylights, and other features cause variations from the usual framing arrangement. Design drawings present the general layout and all basic dimensions along with design stresses and "make-up" of members. All rivet sizes, specifications, and descriptions of splices and other special features must be included.

Before starting the drawing, the base, rise, length, and bevel of all skeleton or working lines should be

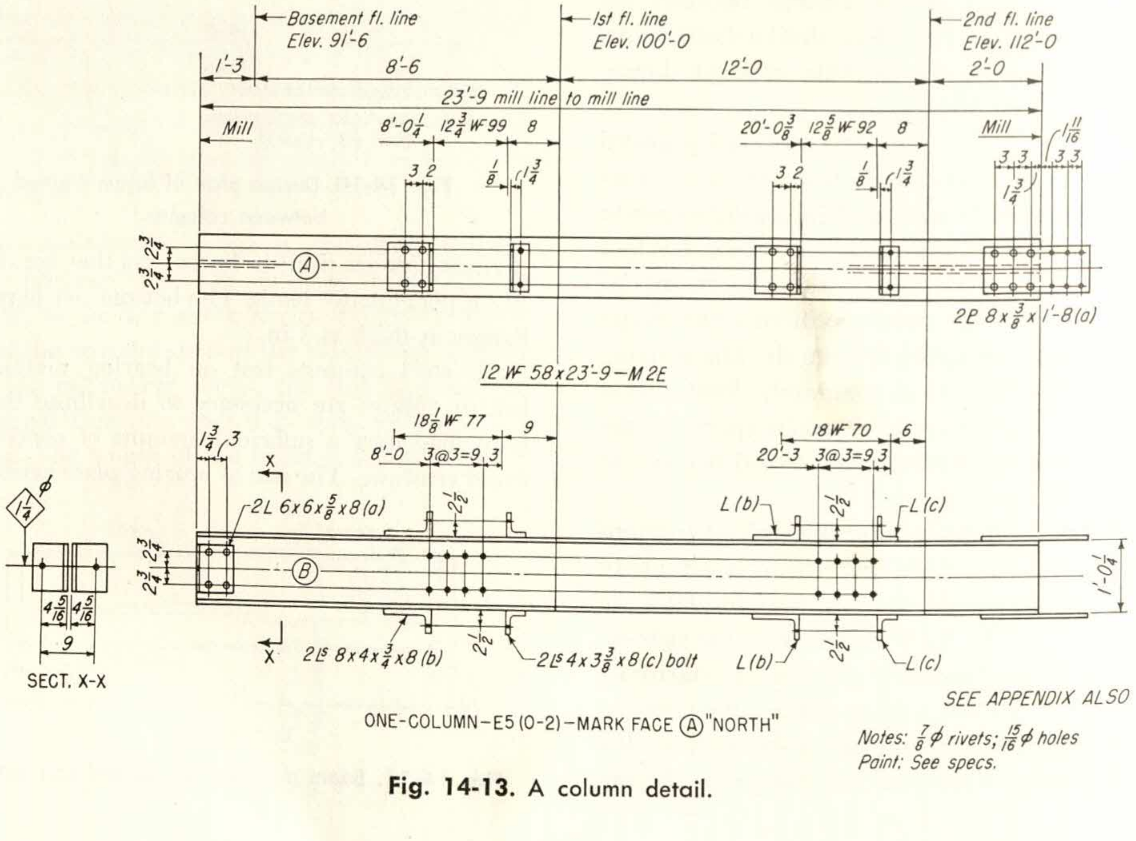


Fig. 14-13. A column detail.

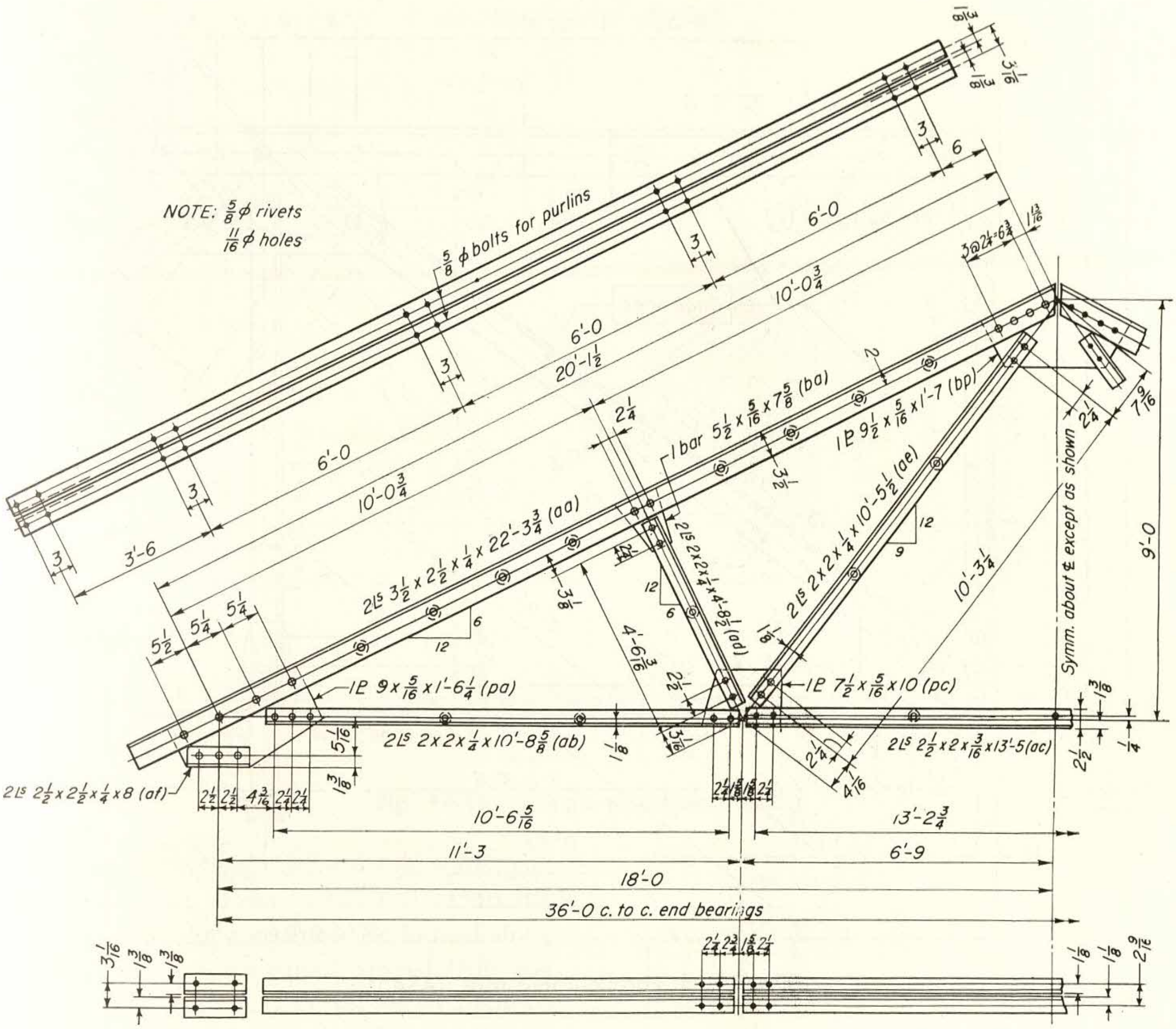

NOTE: 5/8 φ rivets
11/16 φ holes
5/8 φ bolts for purlins
6'-0
6'-0
6'-0
3'-6
3
3
3
3
3
6
10'-0 3/4
10'-0 3/4
20'-1 1/2
3@2 1/4=6 3/4
1 13/16
2 1/4
1 bar 5 1/2 x 5/16 x 7 5/8 (ba)
1 ℘ 9 1/2 x 5/16 x 1'-7 (bp)
2∟s 3 1/2 x 2 1/2 x 1/4 x 22'-3 3/4 (aa)
2∟s 2x2x1/4x4'-8 1/2 (ad)
2∟s 2 x 2 x 1/4 x 10'-5 1/2 (ae)
10'-3 1/4
4'-6 3/16
12
6
12
9
Symm. about ℄ except as shown
9'-0
7 9/16
1 ℘ 9 x 5/16 x 1'-6 1/4 (pa)
1 ℘ 7 1/2 x 5/16 x 10 (pc)
2∟s 2x2x1/4x10'-8 5/8 (ab)
2∟s 2 1/2 x 2 x 3/16 x 13'-5 (ac)
2∟s 2 1/2 x 2 1/2 x 1/4 x 8 (af)
5 1/2
5 1/4
5 1/4
5 1/16
3 1/8
2 1/4
2 1/4
4 3/16
2 1/4
2 1/4
10'-6 5/16
13'-2 3/4
11'-3
6'-9
18'-0
36'-0 c. to c. end bearings
3 1/16
1 1/8
2 1/2
1 1/4
2 9/16

Fig. 14-14. Roof-truss details.

determined to the nearest 1/16 in. While the student may choose to use logarithms, a copy of Smoley's "Tables of Logarithms and Squares" and "Slopes and Rises" or Inskip's "Squares, Logarithms, and Coordinates" is indispensable to the professional draftsman. If along a sloping member a right triangle, with one leg horizontal and the other vertical, is formed, the bevel will be the length of the shorter leg when the longer one is taken as 12 in. (see Fig. 14-14). Shop personnel always work with the bevel of sloping lines, never with angles measured in radians or degrees. Bevels are useful in dimensioning joints.

Since most roof trusses are symmetrical, only one-half of a truss need be shown in a drawing. An elevation, a plan view of the top chord, and a plan view of the bottom chord are the three views always included. A suitable scale, 3/8" = 1' or 1/2" = 1', is selected for drawing working lines for the elevation. A larger scale, 3/4" = 1' or 1" = 1', is selected for drawing the details. An enlarged scale that would show joint details overlapping is to be avoided. An unnecessarily small scale will retard a draftsman's speed and make his drawings difficult to read. Working lines serve as gage lines and members are drawn about them. A clearance of 1/4 in. is left between all members (see Fig. 14-15).

14-10. Detailing joints for single plane trusses. With a clear understanding of basic principles, joints can be quickly and easily detailed. The objective is to provide sufficient strength and adequate clearances while holding material and shop-labor costs to a minimum. Gusset plates are cut from rectangular stock: the smaller and simpler in shape

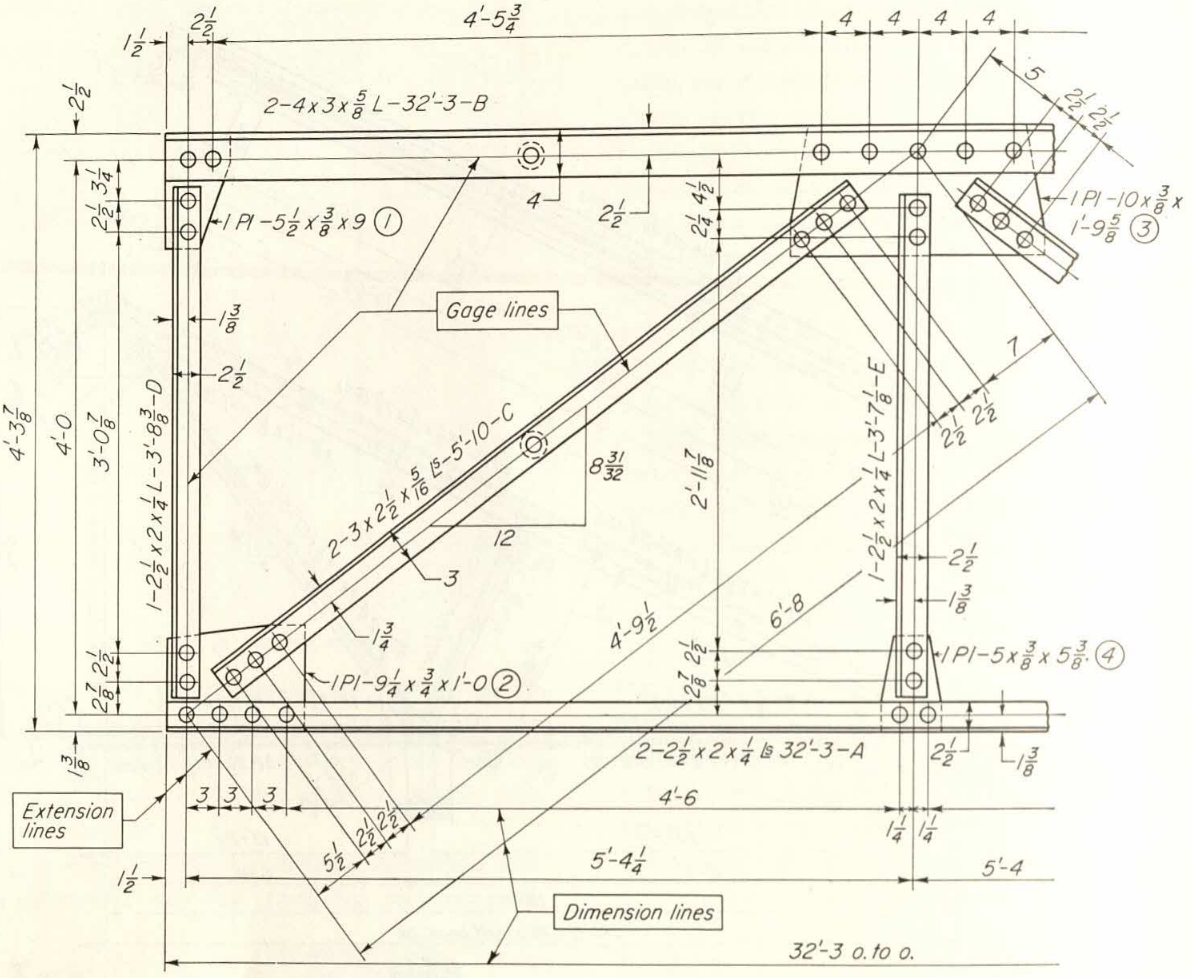


Fig. 14-15. Parallel-chord truss. (ASA.)

the plate, the lower the material cost. Labor costs involve making the template, cutting the plate, punching holes, and driving rivets. It must be kept in mind that cutting a rectangular plate to a trapezoidal shape does not save material but instead requires an extra cut.

Figure 14-16 illustrates the procedure in detailing joints. The width of the plate is determined by the spacing of the rivets in the member (at the left) with the steepest slope. Therefore, the edge distance and the spacing of the rivets in the 3 × 2 × 5/16 Ls will be held to a minimum. By inspection, the distance from *a* to *b* is the sum of two rivet spaces plus an edge distance plus the base of one triangle and the slope of another. Rivet *c* can be placed opposite rivet *a*. Rivets *d* and *e* are customarily placed below rivets *a* and *c*, respectively. Spaces *bd* and *be* are increased until a multiple of 1/4 in. is reached. The size of the gusset plate is obtained by increasing distances *ad* and *de* to provide edge distances on the plate.

14-11. Scales. Structural drawings should never be scaled (measured by the workman). Since all essential dimensions must be shown, scaling is not necessary. Exaggeration or enlargement of small parts and other details is customarily practiced for the sake of clarity and convenience. The thickness of flanges and webs may be exaggerated as desired. Fillets and rounded-off toes of flanges are neglected when the scale is 1″ = 1′ or less. It must be kept in mind that material is ordered as billed and the precision with which it is represented on the drawing sheet cannot affect its size or shape. The scales most commonly used for showing details are 3/4″ = 1′ and 1″ = 1′. The actual lengths of beams and columns are not represented to scale. The scales most commonly used for laying out trusses are 1/4″ = 1′, 3/8″ = 1′, and 1/2″ = 1′.

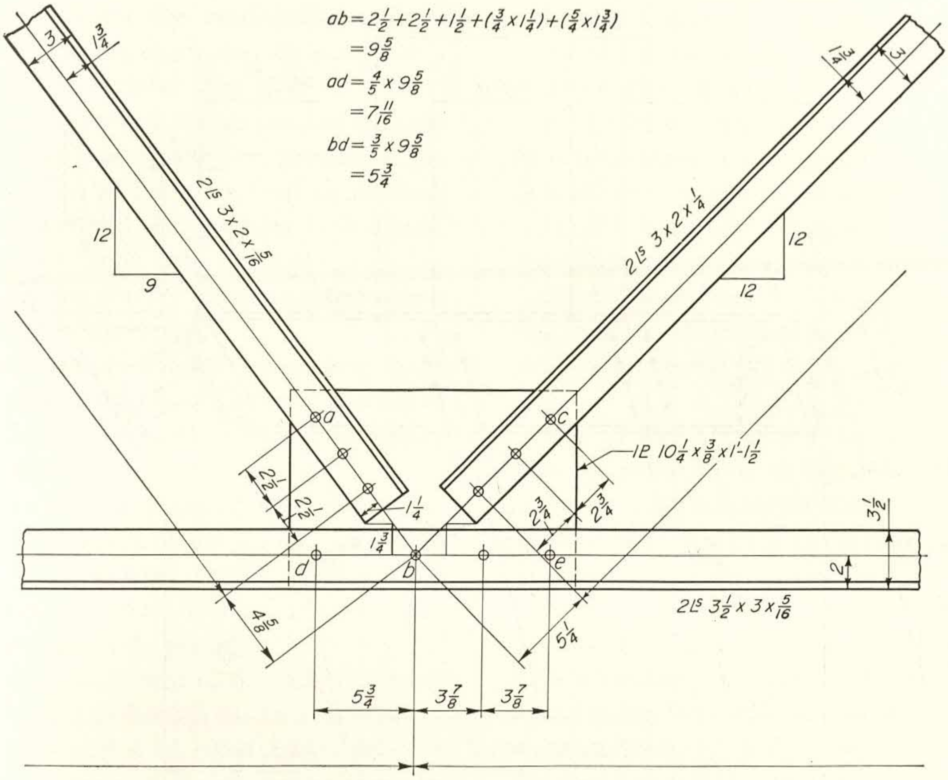


Fig. 14-16. A single-plane-joint detail.

14-12. Use of symbols. Standard signs and symbols for riveting are shown in Fig. 14-17. Only the crossed center line for rivets need be located along gage lines if the rivets are equally spaced. Only one or two rivets at each end of the series need be drawn. The method of representation and dimensioning is shown in Figs. 14-15 and 14-18. Profile views of shop rivets may be omitted entirely. However, all field rivets should be shown in all views. In studying the rivet symbols in Fig. 14-17, note especially that, when an operation is to be performed on the near side (side facing the observer), the defining marks extend outside the circle; the same operation to be performed on the far side is indicated by the same marks confined to the inside of the circle. For welding procedures see Secs. 12-32 to 12-35. Almost all other shop operations are specified in the form of lettered notes.

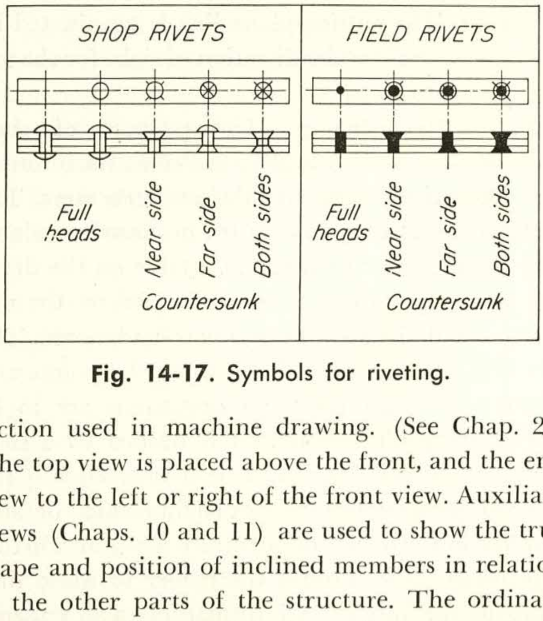


Fig. 14-17. Symbols for riveting.

14-13. Views required. Often a single view of a member will be sufficient to present all the information needed for fabrication. Additional views are required for complex forms such as columns, intricate castings, and weldments.

In the placement and the projection of the views, the procedure is similar to the third-quadrant projection used in machine drawing. (See Chap. 2.) The top view is placed above the front, and the end view to the left or right of the front view. Auxiliary views (Chaps. 10 and 11) are used to show the true shape and position of inclined members in relation to the other parts of the structure. The ordinary bottom view is omitted in favor of a horizontal section looking downward.

Cutting planes to produce section views (Chap. 8) may be passed through structures (and labeled) at any desired position. The section views themselves are also labeled and placed in any convenient area on the drawing sheet. Crosshatching the views

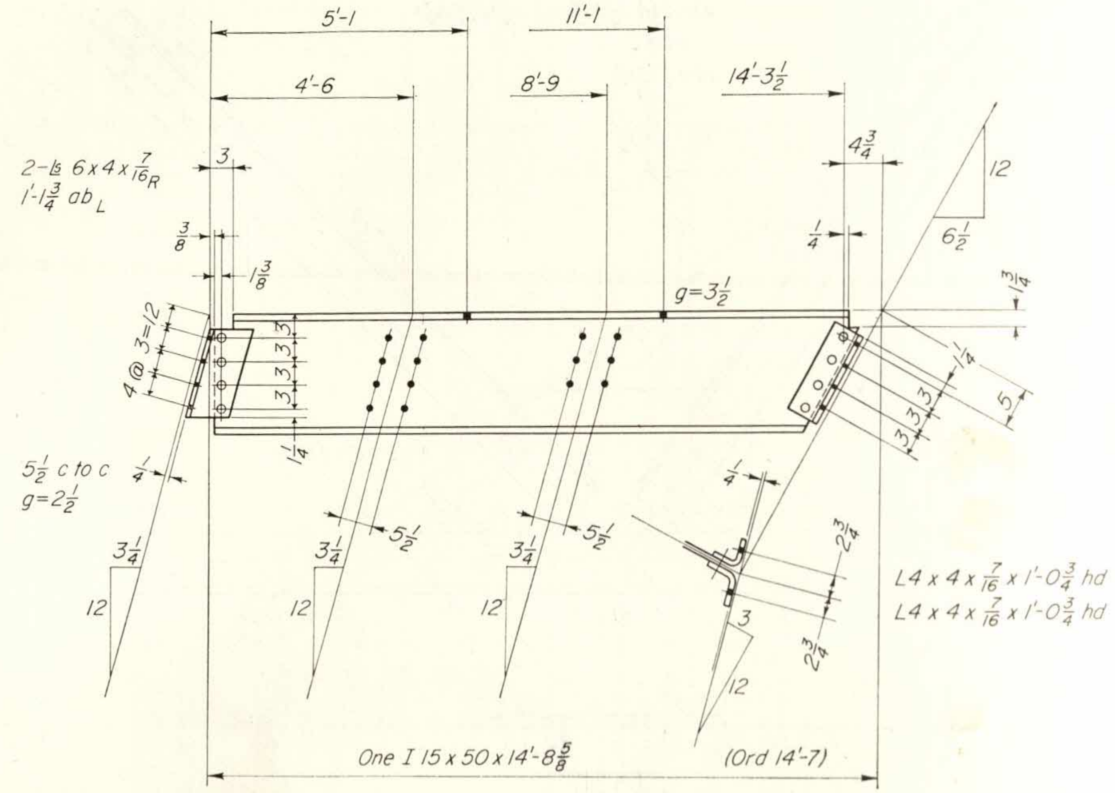


Fig. 14-18. Details of a specially framed beam. (ASA.)

is generally omitted because it is a time-consuming cost item. The cutting-plane line is terminated by arrows which show the direction of sight for the section view produced.

14-14. Dimensioning. The purpose of shop drawings is to convey to shop workmen the information needed by them to fabricate structures. The material for structures is billed on drawings alongside the members or listed in a table on the drawing. Shop operations to be performed on the material are designated by symbols and notes. The function of dimensions is to locate the points and planes on which the shop operations are to be made. Every dimension that is needed by a shop workman or inspector must be shown. Equally important, dimensions must not be duplicated because duplication provides opportunity for contradictory dimensions and requires the reader to waste time studying the duplicated information on an unnecessarily cluttered drawing.

A thorough knowledge of dimensioning can be based only upon an adequate understanding of shop methods and procedures. One may begin by studying good examples. In the drafting room of all fabricators is a file of well-detailed drawings to be consulted by inexperienced draftsmen. The draftsman must keep in mind that it is not sufficient just to dimension structures so that they can be fabricated; instead he must always seek the most economical solution.

The parts of an assembly must be dimensioned closely enough to obtain an adequate fit. Closer tolerances (fits) will add much to cost without serving a useful purpose. Rolling-mill tolerances in cutting structural shapes to length should be observed when possible. Tolerance of ¼ in. in length at each end of such members is generally provided.

Dimensions are ordinarily calculated and specified to the nearest 1/16 in. Multiples of ¼ in. are desirable, with multiples of ⅛ and 1/16 in. being used only as necessary.

The following rules will be helpful in placing dimensions upon drawings:

1. Dimension lines and leaders are thin straight unbroken lines terminating in arrows that touch extension lines or the part itself.

2. The figures of dimensions are placed above and near the midpoint of dimension lines. In limited spaces, the figure may be placed as seen in Figs.

14-15 and 14-18. Notes may read horizontally or vertically (from the right) or may be placed on a slope related to the member they refer to.

3. The line between the numerator and denominator of fractions is always drawn parallel to the dimension line and at the same level as the dash separating the feet and inch number in a dimension. Dimensions and notes should never be crowded. Letters for notes or figures for dimensions should always be in the clear.

4. Lines of dimensions should be no closer to the outlines of members than $\frac{5}{8}$ in. Where a number of lines of dimensions occur, they should be spaced about $\frac{5}{16}$ in. apart.

5. Distances between points greater than 12 in. are expressed thus: $6' - 8$, $6' - 0\frac{1}{2}$, or $6' - 0$. Nominal material sizes, such as widths of plates and depths of shapes, are given in inches, for example, 14 WF beams or $62\frac{1}{2} \times \frac{3}{8}$ plates.

6. The inch mark is omitted for inches alone or when both feet and inches appear in a dimension.

7. When the number of equal spaces between rivet centers exceeds three, the dimension gives the number of spaces, the length of the space, and the distance between the end rivets in that series.

8. The location of all field rivets must always be shown with respect to each other.

9. The assembly mark (identification symbols) is always placed close to the part itself.

10. The working lines for truss members are used as gage lines. The intersections of working lines establish working points.

11. Gage lines (the lines on which rivet holes appear) are drawn as thin solid lines.

12. The slope or bevel of members is indicated by the actual drawing of a right-angle triangle at the member. (See Fig. 14-18.)

13. Entire distances between working points must be given; details adjacent to working points may be dimensioned in relation to each other.

14. All detail dimensions, when added together, must check with their over-all dimensions.

15. All dimensions are calculated to the nearest $\frac{1}{16}$ in. Bevel dimensions in bridge work should be held to the nearest $\frac{1}{32}$ in.

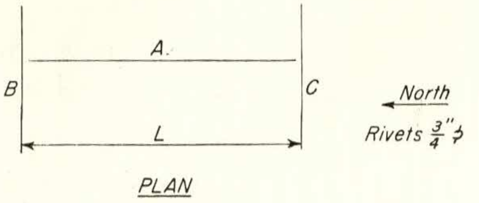
Most of these rules are illustrated on the inclined member at the center of Fig. 14-15. Angles *c* in the figure serve as an example of how a member should be dimensioned. The width of the angles (3 in.) is given so that the shop will know which legs to place back to back. The gage distance ($1\frac{3}{4}$ in.) from the heels of the angles to the gage line is dimensioned. This is essential because at times the "usual gages" found in the steel manual cannot be used. The dimension ($4' - 9\frac{1}{2}$) is shown because it is needed in the shop to establish working points for the angles. Other rivets adjacent to or between end rivets will be located from these working points. The bevel ($8\frac{31}{32}$ in 12) is shown beside the member. The number of angles required and their dimensions (with the symbol identifying the member) appear in the expression ($2 - 3 \times 2\frac{1}{2} \times \frac{5}{16} \measuredangle - 5' - 10 - c$) placed just above the unit. The dimensions ($5\frac{1}{2}$ and 7) are the distances from the end rivets on the member to the working points on the truss.

PROBLEMS

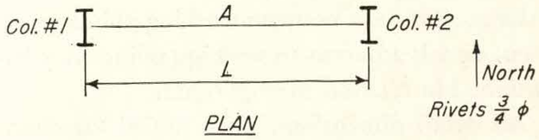
Make shop details for beam *A* (see figure) shown framing into girders *B* and *C*. Use standard connections. Refer to Figs. 14-6 and 14-7*a* in the text and suitable tables in the Appendix.

PROBS.	Beam			Length *L*, ft
	A	*B*	*C*	
14-1	24 WF 94	36 WF 280	30 WF 132	26
14-2	16 WF 88	24 WF 94	24 WF 76	19
14-3	16 WF 58	30 WF 124	30 WF 116	17

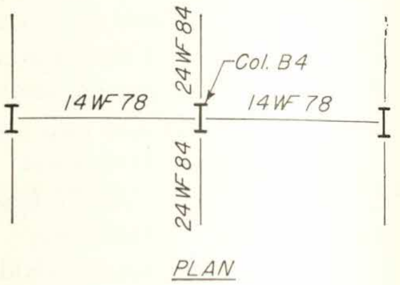
Elevation, top of steel (beams A, B, C) = 81′-6



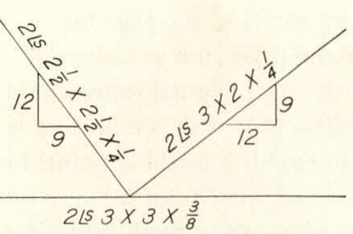
Make shop details for beam *A* (see figure) framed between columns 1 and 2. Use standard connections. Refer to Figs. 14-6 and 14-7*a* and tables in the Appendix.



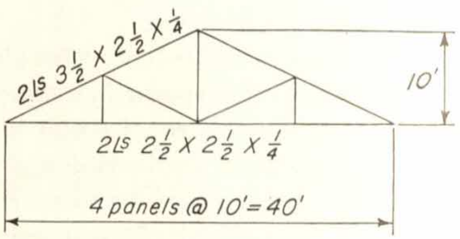
PROBS.	Beam *A*	Column		Length *L*, ft
		1	2	
14-4	24 WF 94	14 WF 84	14 WF 78	28
14-5	16 WF 88	14 WF 53	14 WF 34	20
14-6	16 WF 58	12 WF 58	12 WF 40	16



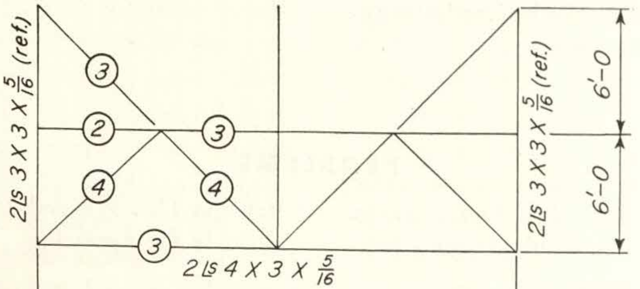
14-7. The framing plan shown in the figure is typical for floors 3 and 4. Prepare shop details of column B4 using Fig. 14-13 as a guide.



14-8. Prepare shop detail drawings for the single-plane-truss connections shown in the figure. Three ¾-in.-diameter rivets are required to connect each pair of angles. Use a ⅜-in. (thick) gusset plate, and provide ¼-in. clearance between the angles. Refer to Fig. 14-16. (The thin lines in the problem figure are the working lines for your drawing.)



14-9. Using Fig. 14-14 as a guide, construct a shop drawing for the roof truss shown in the problem figure. The internal bracing members consist of pairs of 2 × 2 × ¼ ∠s. (Since the structure is symmetrical, only a one-half elevation need be drawn.)



14-10. Prepare shop details for the sway frame shown in the figure. (The sway frame is used as bracing between main roof trusses.) The number of ¾-in. rivets required at each joint to connect them is shown encircled on the working line for each member. Unless otherwise indicated, all members consist of 2 ∠s 3½ × 3 × 5/16. For drawing suggestions, see Figs. 14-14 and 14-15.

Chapter 15

DESCRIPTIVE GEOMETRY

15-1. Descriptive geometry. Descriptive geometry deals with the representation of space magnitudes and the solution of problems involving these "in space" relationships. Solutions may be analytical (mathematical) or graphical (representational, their treatment in this chapter). The elements that serve our purposes are points, lines, and surfaces. Since all machine parts and engineering structures are similar in shape to geometric forms like the prism, pyramid, cylinder, cone, and sphere, we should think of points, lines, and planes as the elements of the form we are representing when producing any complete engineering drawing. The work covered in this chapter is to be considered an extension of that covered in Chaps. 2, 9, and 10. Thus, a thorough understanding of the principles of orthographic projection employed in constructing primary and auxiliary views is necessary before attempting to solve the problems set forth herein. The securing of a solution will depend on an accurate analysis of the problem and the correct projection procedure. The degree of accuracy obtained is contingent upon the patience and diligence of the particular draftsman.

15-2. The point in space. Since a point may be considered a definite location of a certain spot in space, as the intersection of two lines, or the intersection of three noncollinear planes, it may be located in the principal views (the front, top, and side), as indicated in both pictorials of Fig. 15-1. A point may also be projected from the principal views to the primary (1-) and secondary (2-) aux-

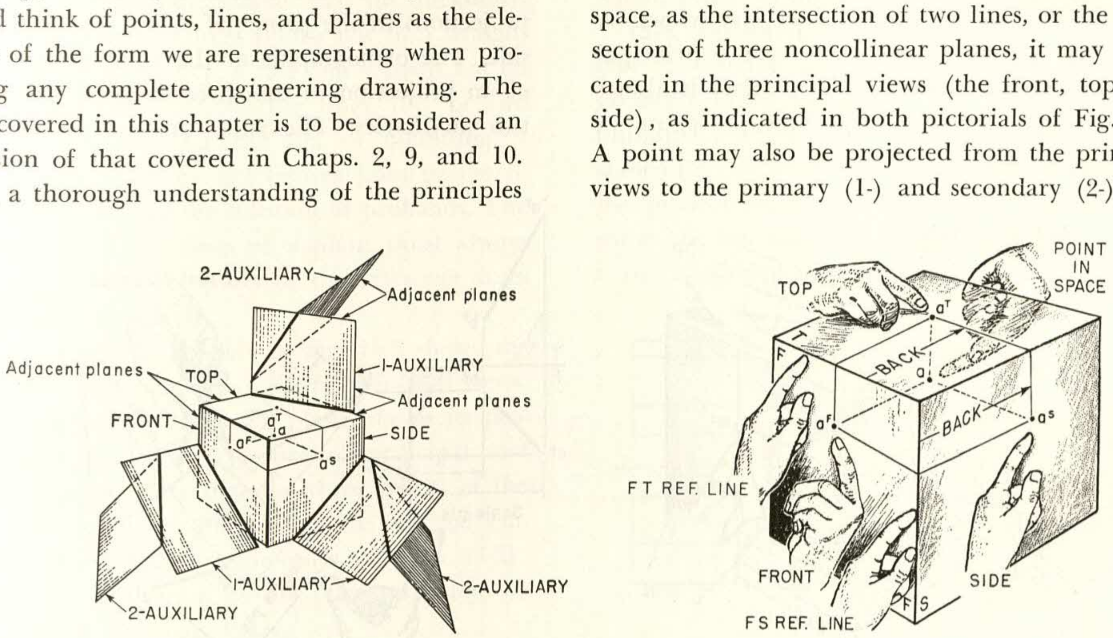
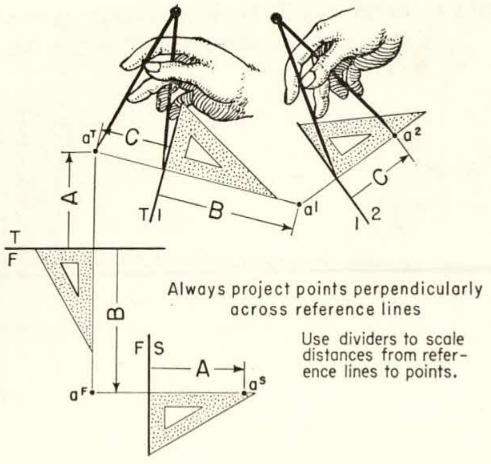


Fig. 15-1. The point in space.



Always project points perpendicularly across reference lines

Use dividers to scale distances from reference lines to points.

Fig. 15-2. Locating a point in successive views.

iliaries, and back from the auxiliaries to the principal views when the solution of a problem calls for this procedure. In order to locate a point in space, at least two views of it are required, either a pair of adjacent views, or the extreme views of any combination of three consecutive views (the front and side, front and top, top and 1-auxiliary, and the 1- and 2-auxiliaries could be considered adjacent views). Two views may be said to be adjacent when they have a common reference line between them. The reference line separates adjacent (any two consecutive) views.

The side, front, and top; the front, top, and 1-auxiliary; and the top, 1-auxiliary, and 2-auxiliary are combinations of three consecutive views. A 1-auxiliary is always projected from a principal view (top, front, or side). A 2-auxiliary is always projected from a 1-auxiliary. This procedure in projection must never be violated. Since each succeeding view (moving from the principal views to the auxiliaries or back from the auxiliaries to the principal views) is perpendicular in space to the preceding or adjacent view, the points are projected perpendicularly (at right angles) across the folding or reference line. The distance from the reference line to the point on its projector in any newly drawn view is equal to the distance from the reference line to the point in any view adjacent to the view from which the point was projected to its new position. The two extreme views of a group of three consecutive views are related views, or, stated in another way, any two views adjacent to the same view are said to be related views. The distance from a particular point to its reference line is equal in the extreme views of any combination of three consecutive views.

In Fig. 15-2, distance *A* in the side is equal to *A* in the top, *B* in the front is equal to *B* in the 1-auxiliary, and *C* in the top is equal to *C* in the 2-auxiliary.

15-3. The line in space. By definition, a line is the path of a moving point. A straight line is located in space by a point and a direction or by any two points on its path of length, location, or direction. (A straight line may be the intersection of two planes.) The pictorial at the left in Fig. 15-3 pictures a line *mn* in space and shows its projections in the principal views, top, front, and side. The orthographic at the right shows a line *ab* in projection in the three principal views and two auxiliaries. The rules that govern the pro-

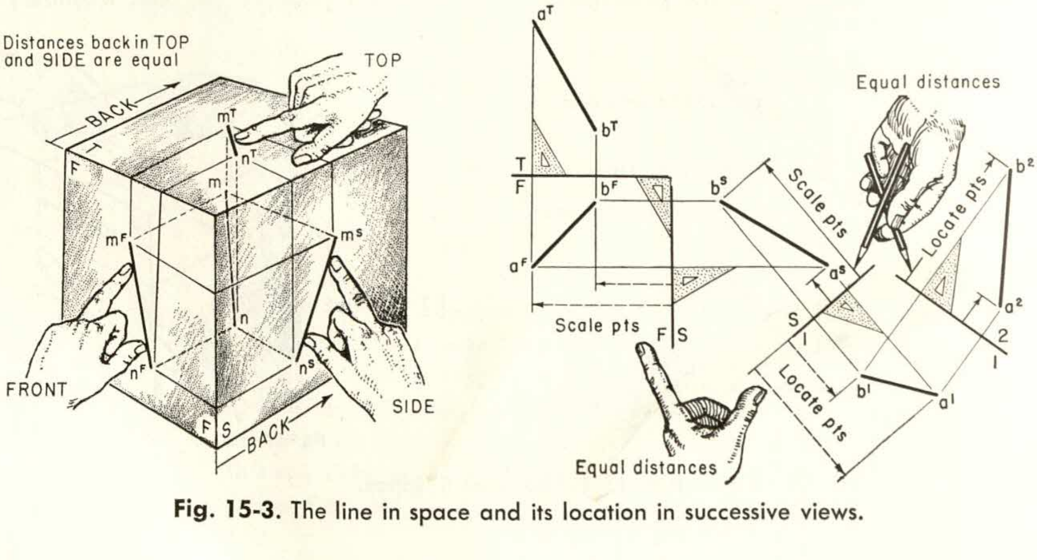


Fig. 15-3. The line in space and its location in successive views.

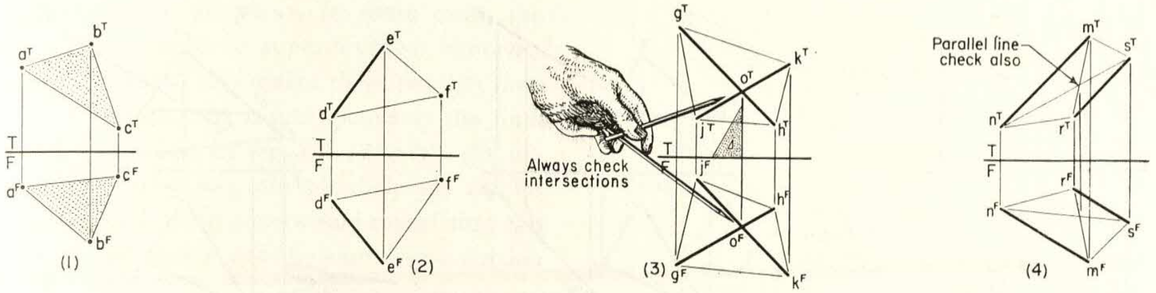


Fig. 15-4. Representation of a plane surface.

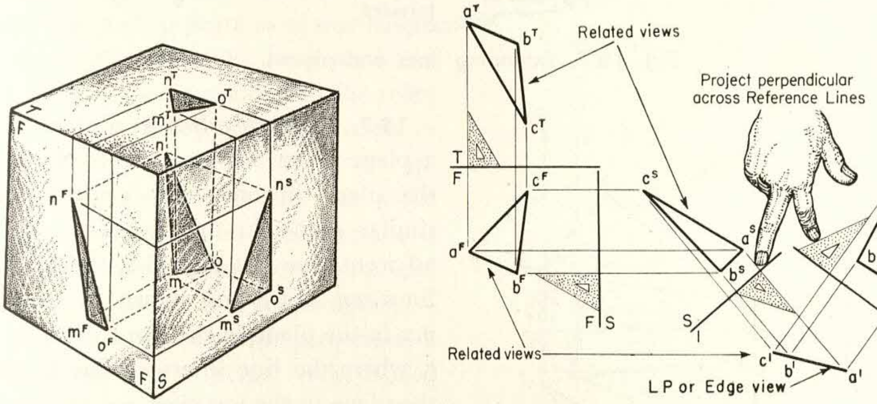


Fig. 15-5. The plane in space and its location in successive views.

jection of a single point from one view to another also govern the projecting of the two points of the line *ab* from one view to its neighbor.

15-4. The plane in space. A plane is a flat surface. It is two-dimensional (has no thickness). It is represented by three points not in a straight line (see Fig. 15-4) (1), a line and a point not on the line (2), two intersecting lines (3), or two parallel lines (4). Closing up, or bounding, a plane as suggested by the lighter lines in the illustration facilitates the solution of problems. The intersections of the lines of a plane must always project perpendicularly across the reference lines of all adjacent views.

The pictorial at the left in Fig. 15-5 shows the projections of a plane *mno* in the principal views. The orthographic shows the plane *abc* as its projections appear in a sequence of principal and auxiliary views. Note that the three points of the plane are projected similarly to the method employed in projecting a single point (see Sec. 15-2). Observe the projection of the plane as a line or edge view in the 1-auxiliary.

15-5. A geometric solid in space. Projecting most solids into succeeding views usually requires only the projecting of the points of the planes that delineate its external and internal surfaces. In Fig. 15-6, the direction distances *A* in the top and side are equal, *B* in the front and 1-auxiliary are equal, and *C* in the side and 2-auxiliary are equal.

15-6. Extending lines and planes. For the purpose of solving certain problems in descriptive geometry, lines and planes may be considered as unlimited in their extent. In (1) of Fig. 15-7 are shown the line with its limiting points *m* and *n* and the plane limited by the points *a, b,* and *c.* (2) shows the line extended at both ends to the points *r* and *s,* which project perpendicularly across the

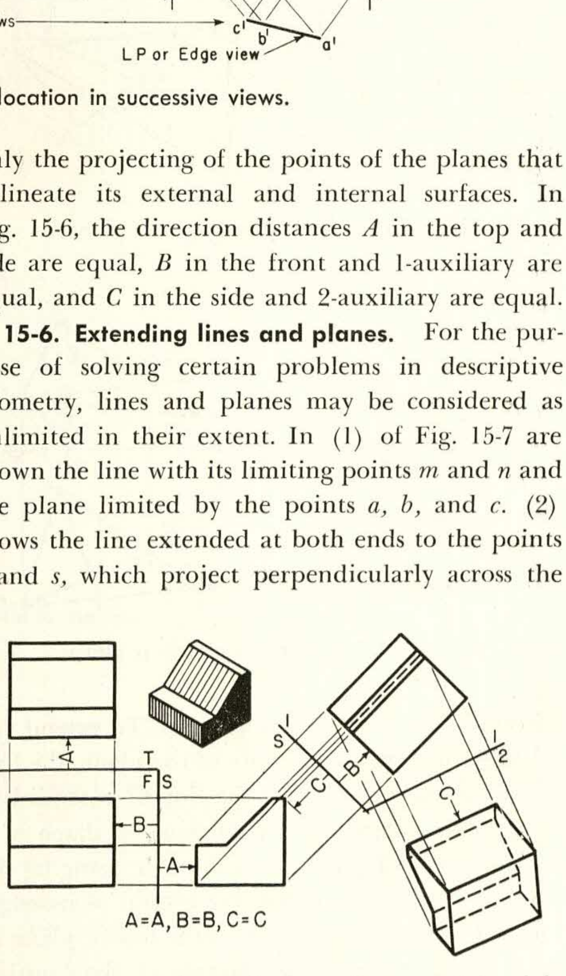


Fig. 15-6. Successive projections of a geometric solid.

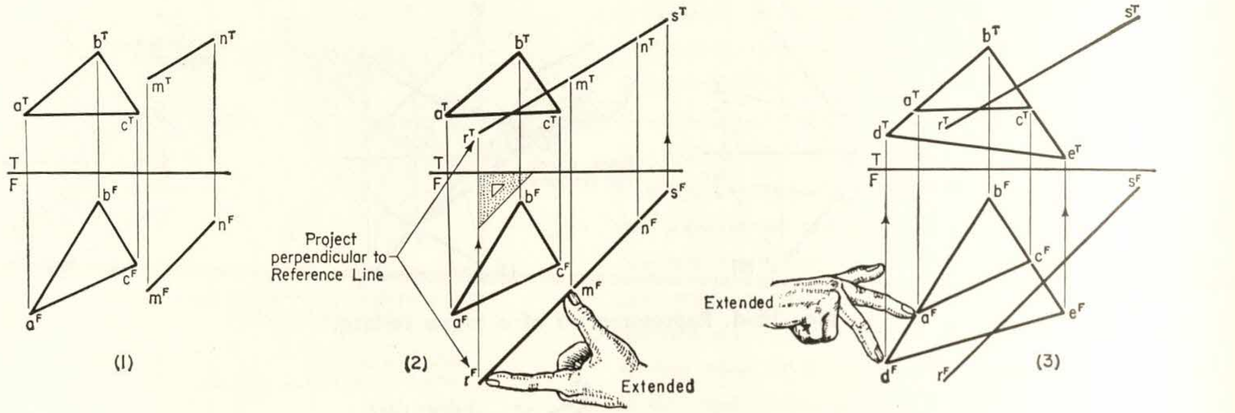


Fig. 15-7. Extending lines and planes.

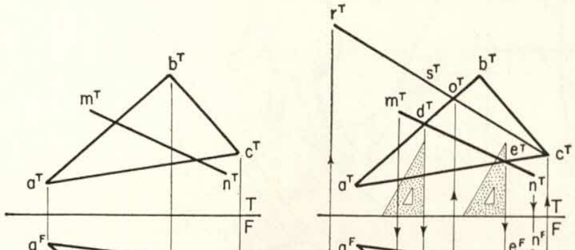


Fig. 15-8. Locating a line in a plane.

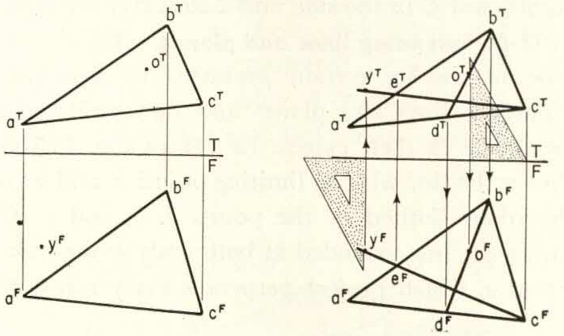


Fig. 15-9. Locating a point in a plane.

reference line of the adjacent views. To extend (or enlarge) the bounded surface of the plane, the line *ab* was extended to *d* and the line *bc* extended to *e* (3). Extending a line, changing the shape of a plane by extending one of its lines, or changing the shape of a plane by extending several of its edges does not change the position of the line or plane in space if the respective projections of the limiting points of their extended portions are in perpendicular projection in adjacent views.

15-7. Locating a line in a plane. A line lies in a plane when any two points of the line lying in the plane in one view project, respectively, to similar points in the plane in any succeeding or adjacent view. In Fig. 15-8, the plane *abc* and the lines *mn* and *rs* are shown, at the left. To locate *mn* in the plane in the front view, the points *d* and *e*, where the line intersects the boundary lines of the plane in the top view, are projected to the front view, where *mn* is located by drawing it through these points. Line *rs* is extended in the front view to intersect the boundary lines of the plane at *o* and *c*. These points are then projected to the top view, where the line has been drawn from *c* through *o* to *r*, which is the respective projection of *r* from the front view. Note that the intersections *d* and *e* and *c* and *o* of the given lines with the boundary lines of the plane determine the locations of the lines in the adjacent views.

15-8. Locating a point in a plane. A point lies in a plane when it is located on a line in the plane. In Fig. 15-9, the plane *abc* and the points *o* and *y* presumed lying in the plane are given at the left. At the right, a line *bd* is drawn in the plane through point *o* in the top view. The line is projected to the front view, where point *o* has also been projected to its corresponding position on the line. To locate point *y* in the plane, a line (*c* containing *y* and intersecting the boundary at *e*) has been drawn in the front view, then projected to the top view, where the point *y* has been located in its proper corresponding position on the line.

15-9. Parallel lines. Lines that are parallel to each other in space will project parallel in all views of projection. In studying the projections of the object in Fig. 15-6, it will be noted that the lines of the object that are parallel to each other project parallel in all views. In some cases, the lines appear as points or superimposed. However, this latter condition also makes them parallel lines (see Fig. 15-10 also). A casual glance at the lines *ab* and *cd* at the left in Fig. 15-11 conveys the impression that they, too, are parallel; yet careful visualization or a third view would reveal that this apparent parallelism is not the case (right portion of figure).

15-10. Lines parallel to views. In Fig. 15-12, (1) the frontal line *ab* in the top view lies parallel to the reference line and appears as a true-length projection in the front view. The horizontal line *ac* in the front view, which is parallel to the reference line, appears as a true-length projection in the top view. The profile lines *de* and *gj* (2) appear as true-length projections in the side view. In (3), the frontal line *rx* in the plane *xyz* shows as a true-length projection in the front view, and the horizontal line *wz* shows as a true-length projection in the top view. When a line projects as a true-length projection in a principal view, it also reveals the angle it makes with a principal plane of projection (see Fig. 15-13). The angle between a line and a plane is seen in the view that shows

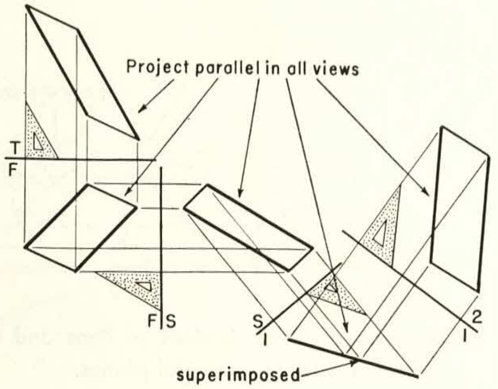


Fig. 15-10. Projections of parallel lines.

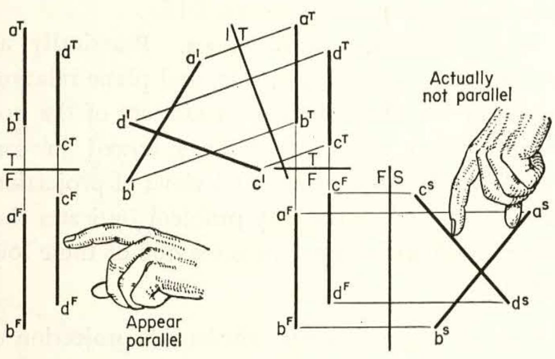


Fig. 15-11. Projections of nonparallel lines.

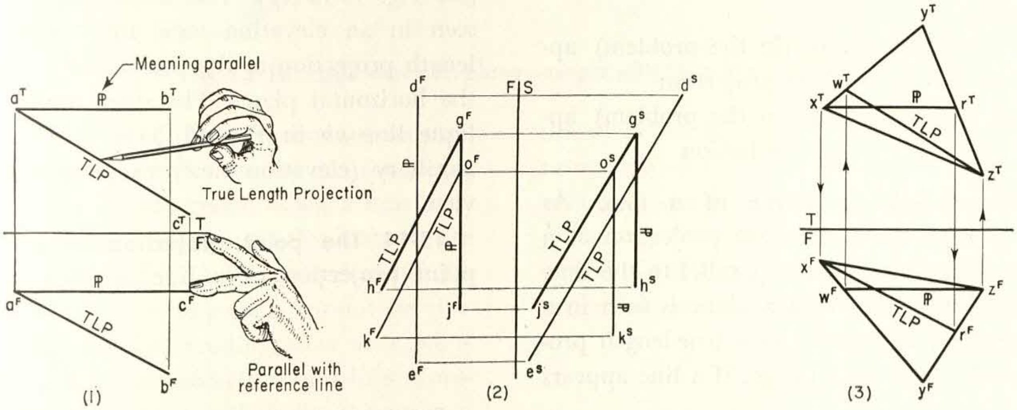


Fig. 15-12. Lines parallel to views.

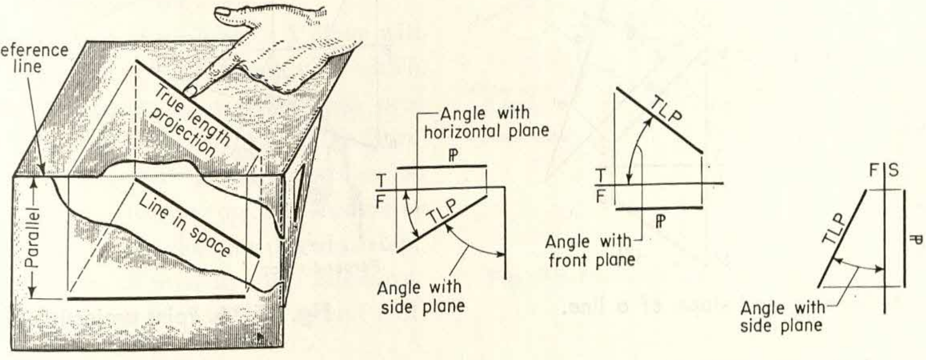


Fig. 15-13. True-length projections of lines and their angles with the principal planes.

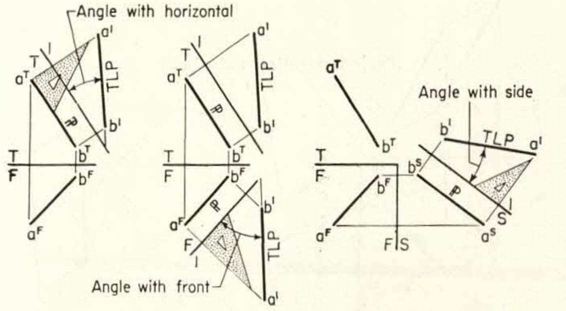


Fig. 15-14. True-length projections of lines and their angles with the principal planes.

the true-length projection of the line and the edge view of the plane. See also Sec. 2-16.

15-11. The four basic views. Practically all problems involving point, line, and plane relationships can be solved through a mastery of the procedure which must always be followed in constructing the four fundamental views of projection. The analysis of almost any problem indicates that the solution will appear in some one of these four views:

1. A view showing the true-length projection of a line (in the problem)
2. A view where a line (in the problem) appears as a point projection
3. A view where a plane (in the problem) appears as an edge or line projection
4. A view where a plane (in the problem) appears in its true-shape projection

15-12. True-length projection of a line. As shown previously, the true-length projection of a line is seen in a view that lies parallel to the line. The angle a line makes with a plane is seen in a view where the line appears as a true-length projection and the plane as an edge. If a line appears as a true-length projection in a principal view, the angle it makes with a principal plane of projection can be noted by inspection (Fig. 15-13). However, if a line lies oblique (at an angle) to all three principal planes, its true-length projection and the angle it makes with a principal plane must be found in the proper auxiliary view (see Fig. 15-14). To find the true-length projection and the angle an oblique line makes with the horizontal plane, the 1-auxiliary is projected from the top view. To find the true-length projection and the angle an oblique line makes with the front plane, the 1-auxiliary is projected from the front view. An oblique line projected from the side view appearing as a true-length projection in a 1-auxiliary will show the angle the line makes with the side plane. See discussion on lines in Sec. 2-16.

15-13. Bearing and slope of a line. The bearing of a line is always seen in the top view and is measured in degrees in relation to the angle it makes with a north-south line in that view. The bearing is not affected by the slope of the line; therefore, the line need not necessarily be a true-length projection. Its azimuth is measured in degrees clockwise in relation to the north-south line [see Fig. 15-15 (1)]. The slope angle of a line is seen in an elevation view that shows the true-length projection of the line and the edge view of the horizontal plane. The slope angle of the oblique line *ab* in Fig. 15-15 (2) appears in the 1-auxiliary (elevation view) projected from the top view.

15-14. The point projection of a line. The point projection of a line appears in the view

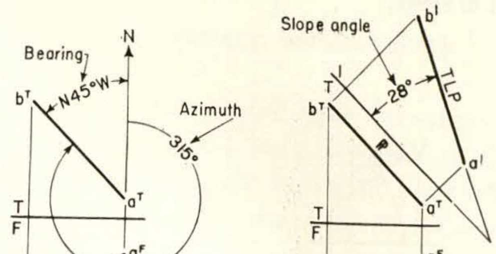


Fig. 15-15. Bearing and slope of a line.

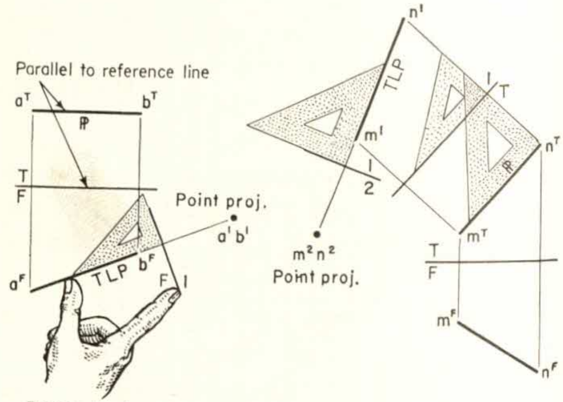


Fig. 15-16. Point projection of a line.

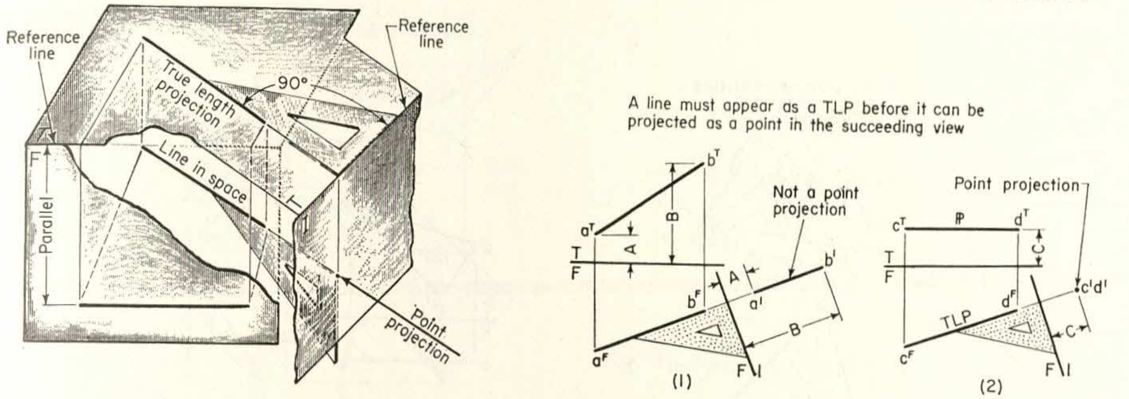


Fig. 15-17. Projections of a line.

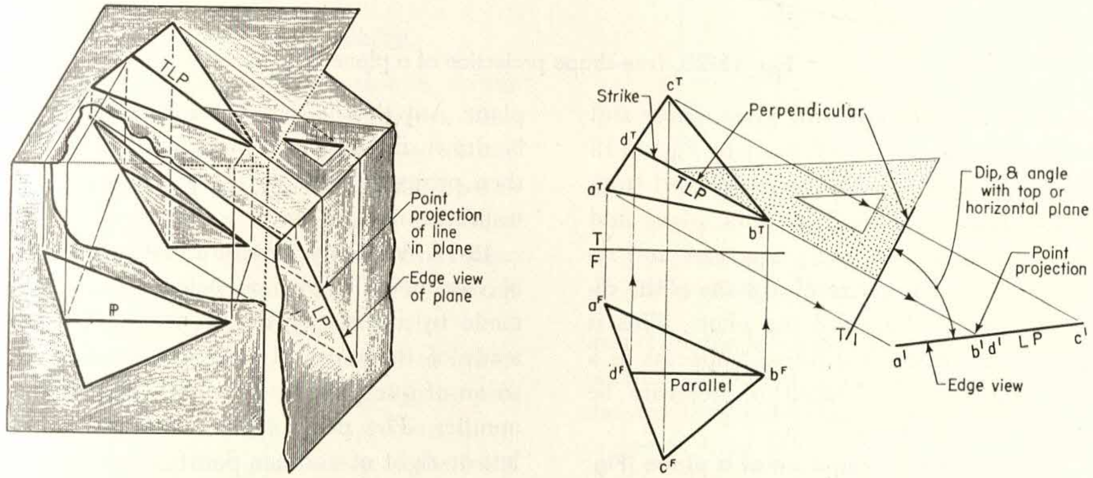


Fig. 15-18. Edge view of a plane—angle with horizontal plane.

passed perpendicular to the view showing its true-length projection. If the line is not in true-length projection in one of the given views, a new view must first be drawn showing it in this manner [see Figs. 15-16 and 15-17 (2)]. A line that does not appear in its true-length projection cannot be projected directly into a succeeding view as a point projection. If the point projection of a line is projected to any new view, it will always appear as a true-length projection lying perpendicular to the reference line for the new view.

15-15. The edge view of a plane. A plane will show as a line projection or edge in that view which shows the point projection of a true-length projection line of the plane. In Fig. 15-18, the horizontal parallel *bd* was placed in the front view of the plane and projected to the top view, where it shows as a true-length projection. In the next step, its point projection was secured in the 1-auxiliary. The respective projections of points *a, b,* and *c* of the plane in this view reveal the plane as a line projection or edge. By the use of front or profile (side) parallels, the edge view of an oblique plane may be secured by projecting from the front or side views (see Fig. 15-19). The dip of a plane appears in an elevation view showing the line pro-

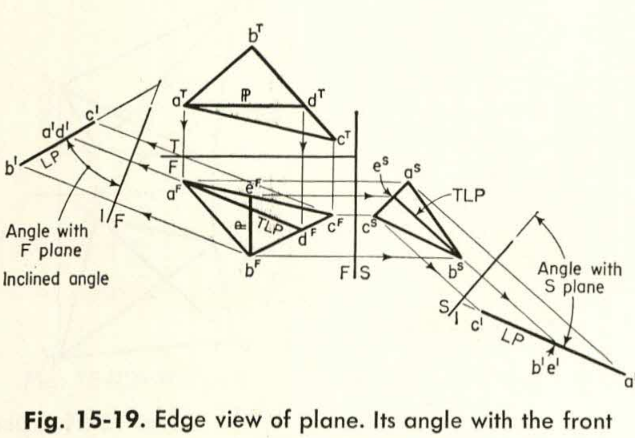


Fig. 15-19. Edge view of plane. Its angle with the front and side planes.

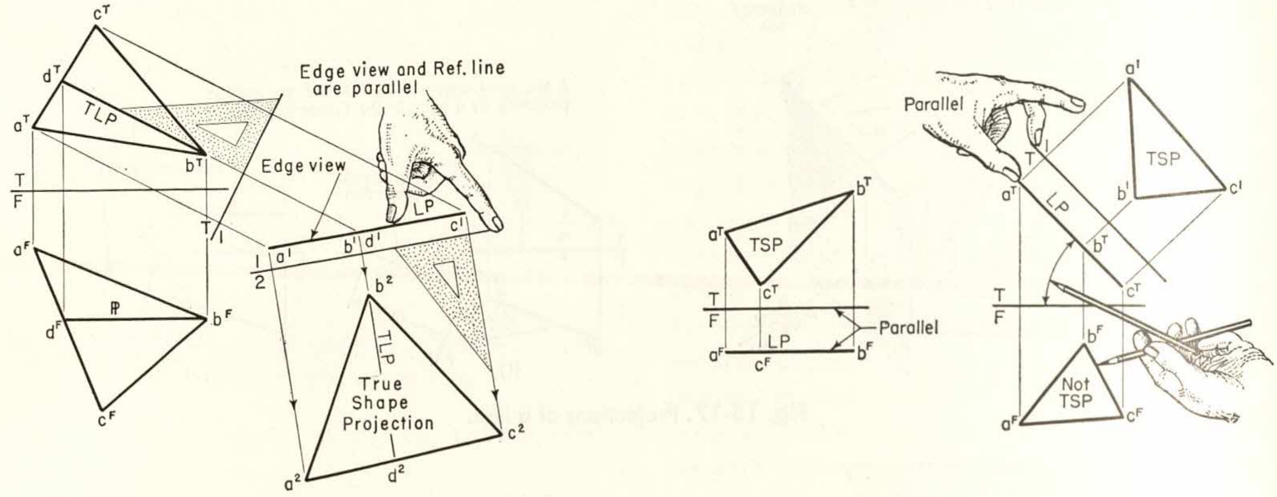
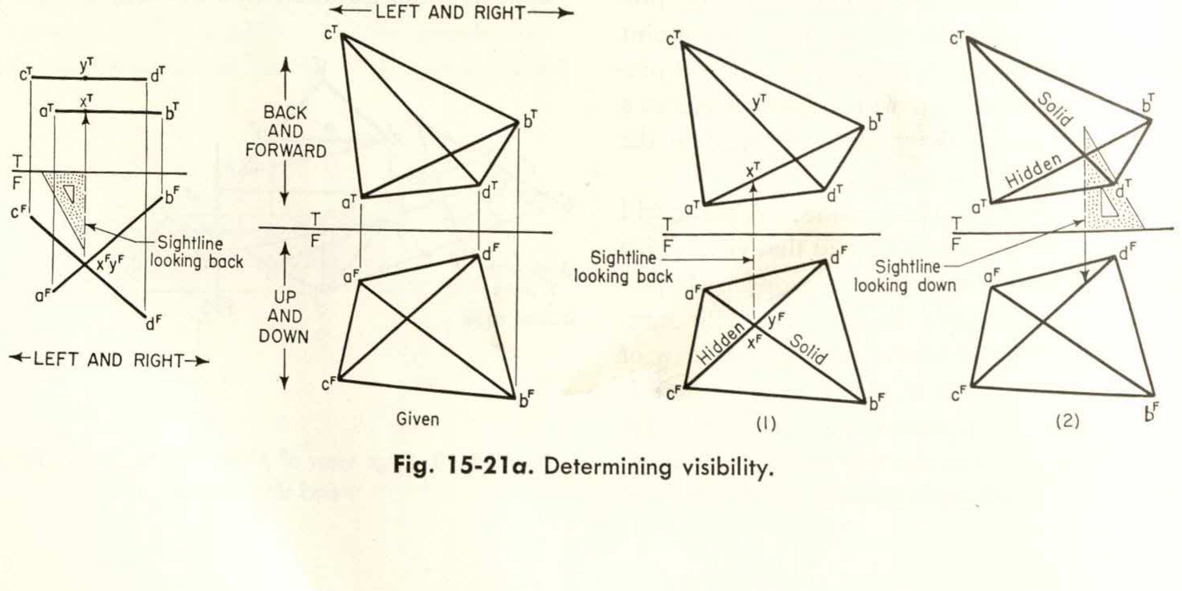


Fig. 15-20. True-shape projection of a plane.

jection or edge views of both the given plane and the horizontal plane. The 1-auxiliary of Fig. 15-18 is an elevation view because it was projected from the top view. Here both the horizontal plane and the given plane appear as line projections and reveal the dip angle. The strike of a plane is the direction of a horizontal line of the plane. This is noted in the view where the line *bd* appears as a true-length projection and must of necessity be seen in a top view (Fig. 15-18).

15-16. The true-shape projection of a plane (Fig. 15-20). A plane appears in its true-shape projection in a view lying parallel to the surface of the plane. To find the true shape of a plane, the reference line for the new view is placed parallel to the line projection or edge view of the given plane. The points of the plane when projected into the new view will reveal the true shape of the plane. Any details that lie in this surface may now be drawn in their true shape and relationship and then projected back to the principal views in the usual manner.

15-17. Visibility. Determination of the position of one point above or below another point is made by inspecting the front and side views. A study of the top and side views indicates the position of one point as nearer or farther back than another. The position of a selected point to the left or right of another point is determined in the top and front views. All external boundary (outermost) lines of a plane or object are solid (unbroken) lines. The visibility of the elements in a view should be established by visualizing the actual positions of points, lines, and planes in their space relationship to each other. However, when seeking which of two lines that appear to intersect is the



Given (1) (2)

Fig. 15-21a. Determining visibility.

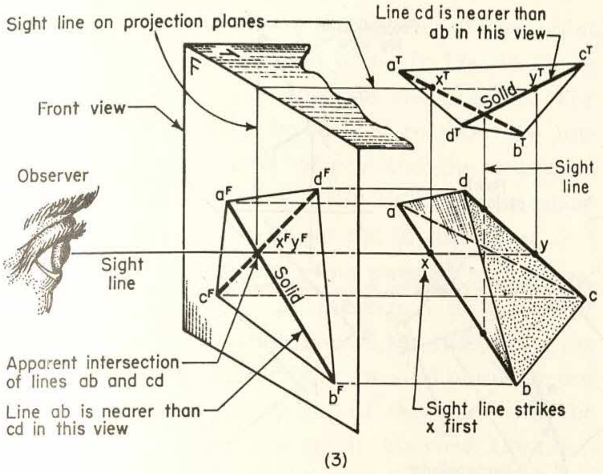

Sight line on projection planes
Line cd is nearer than ab in this view
Front view
F
Observer
Sight line
a^T
x^T
y^T
c^T
Solid
d^T
b^T
Sight line
a^F
d^F
x^Fy^F
Solid
c^F
b^F
a
d
x
y
c
b
Apparent intersection of lines ab and cd
Line ab is nearer than cd in this view
Sight line strikes x first
(3)

Fig. 15-21*b*. Determining visibility.

nearest to you in a view, the solution is accomplished through the very simple procedure illustrated in Fig. 15-21 *a* and *b*, in which lines *ab* and *cd* appear to intersect at *xy*, where the lines cross in the front view. When a sight line is projected through this apparent intersection in the front view, the sight line will strike point *x* and *ab* in the top view before it reaches point *y* and *cd* in that view. Therefore, point *x* and line *ab* are nearer to you in the front view. Repeating the construction by projecting the sight line through the apparent intersection of lines *ab* and *cd* from the top to the front view will reveal *cd* as nearer than *ab* and thus the solid line in the top view (see Fig. 15-21 *a* and *b*).

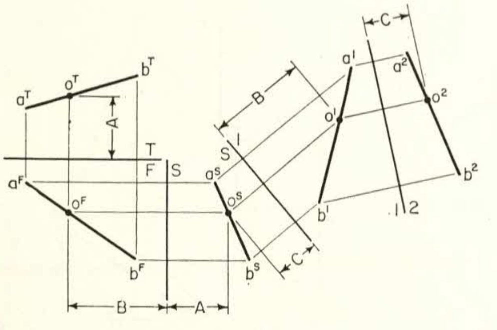


Fig. 15-22*a*. Locating a point on a line in all views.

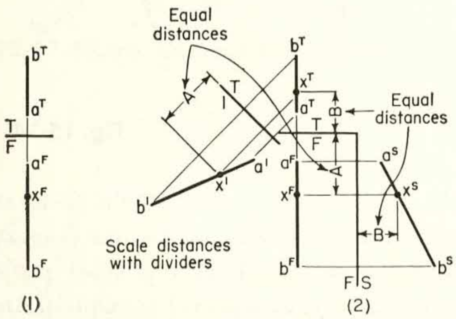


Fig. 15-22*b*. Locating a point on a line.

15-18. Locating a point on a line when given in one view only. If the projection of the oblique line *ab* (Fig. 15-22*a*) were to be given in the principal and the two auxiliary views and the location of the point *o* given only in one, the front view, it would be a simple matter to project the point to all the other views by ordinary projection procedure because the line appears in a manner that makes this readily possible. However, if a line appears in a position whereby a point on it could not be projected to the given adjacent view [such as point *x* on *ab* in the front view of Fig. 15-22*b* (1)], any new view of the line would make it possible to place the point on the line in the top view. A projection of the line to the side view would enable us to locate the point on the line in this view. Then depth distance *B* in the side could be scaled to locate the point on the line in the top view. The auxiliary elevation view of the line would enable us to locate point *x* in the auxiliary because distance *A* is equal in both the front and the auxiliary elevation. The point *x* can now be projected from the auxiliary to the top view [Fig. 15-22*b* (2)].

15-19. Line making required angle with one principal plane. Suppose it were desired to show both projections of the given line *ab* in Fig. 15-23, which makes the (true) angle in space of 30° with the front plane. A new view (1), showing the line in an auxiliary projected from the front view as a true-length projection making an angle of 30°

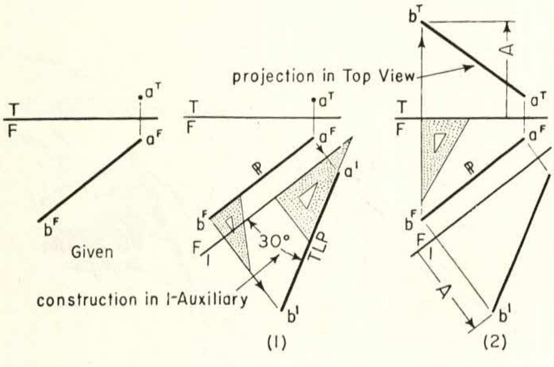


Fig. 15-23. Line making required angle with a principal plane.

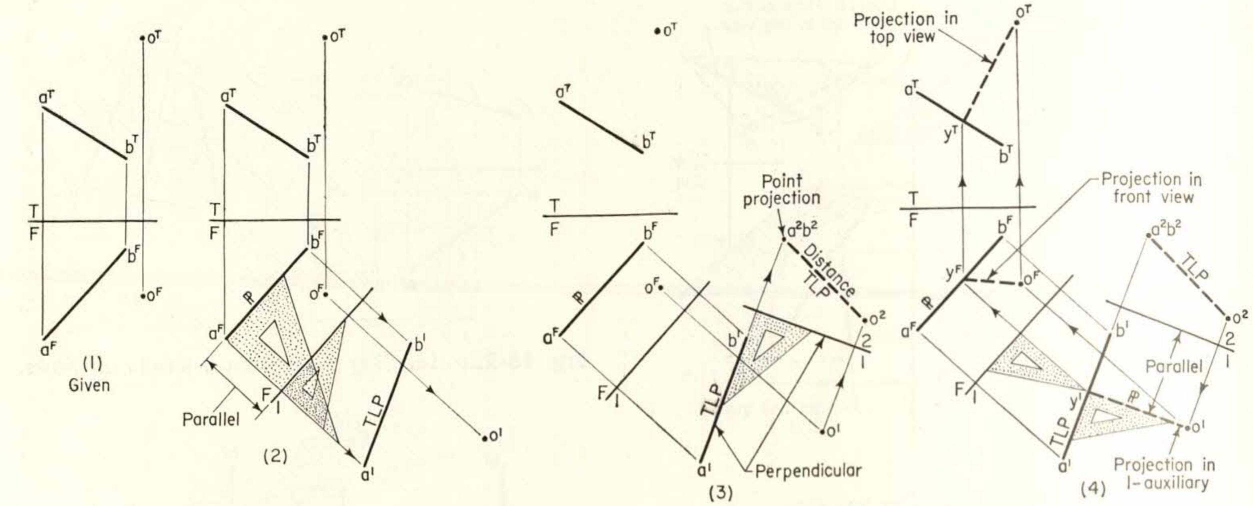


Fig. 15-24. Distance from a point to a line.

with the reference line, would help us locate the proper line. The top view of the line is located by a construction that follows the usual projection procedures [in (2), distances *A* are equal]. Any line making a required angle with the given planes of projection can be located in the same manner if a projection of the line is given in one view and a point of the line is shown in an adjacent view.

15-20. Distance from a point to a line. The distance between a line and a point is seen in the view that shows the point projection of the line and the respective projection of the point. In Fig. 15-24 (1), the line *ab* and the point *o* are given. The first step (2) requires finding the view that shows the true-length projection of the line and the respective projection of the point. The next step (3) shows a view of the point projection of the line and the respective projection of the point. Here the actual distance between them may be measured. The last step (4) reveals how the location or position of the distance is projected back to the previously constructed views. Since the distance is a true-length projection in the 2-auxiliary, it will appear as a line drawn through point *o* parallel to the reference line in the 1-auxiliary. Since a line and a point describe a plane, it would have been possible in this problem to find the true-shape projection view of the plane formed by the line and point, where this distance would appear as a true-length projection drawn through *o* perpendicular to line *ab* in the true-shape projection view (see Fig. 15-25). If required, the location of the distance can be projected back to and shown in the previously constructed views, as indicated.

15-21. Distance from a point to a plane. The view that shows the line projection or edge of a

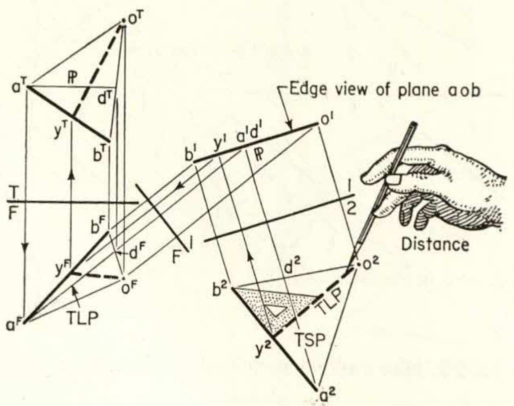


Fig. 15-25. Distance from point to line. Plane method.

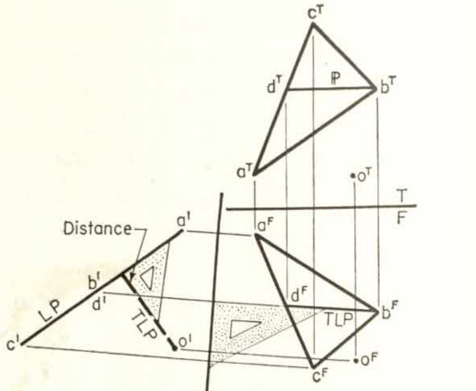


Fig. 15-26. Distance from a point to a plane.

plane and the respective projection of the point shows the distance between them. In Fig. 15-26, let us consider the plane *abc* and the point *o*. The 1-auxiliary has been constructed to show the line projection (edge view) of *abc* and the respective projection of *o*. The distance between the plane and the point may be measured in this view.

15-22. Distance from a line parallel to a plane. A view showing the line projection of the plane and the respective projection of the line shows the distance between them. If the line and plane are not parallel, the piercing point of the line with the plane will become apparent in this view. Considering plane *abc* and the line *mn* in Fig. 15-27, we note that the 1-auxiliary reveals the distance from the line projection of the plane to the line *mn*, which project parallel to each other.

15-23. The distance between parallel planes. A view showing the line projection of a given plane will show the distance between that plane and one that may be parallel to it. If the other plane appears inclined or oblique in this view, the line projection of the given plane contains the line of intersection of the two planes. In Fig. 15-28, when plane *abc* was projected as a line projection in the 1-auxiliary plane, *def* appeared as a line projection also, and parallel to *abc*. The distance between the two planes may be measured in this view.

15-24. Line parallel to a plane. A line is parallel to a plane when it is parallel to any line in the plane. In Fig. 15-29 (at left), the plane *abc* and point *o* are shown in adjacent views, and the top view shows the first step in the solution. Any line *ad* is first drawn in the plane, with *mn* next drawn through point *o* parallel to it. At the right, the line *ad* was projected to its position in the plane in the front view, where line *mn* was drawn through point *o* parallel to it. If desired, a line could have been drawn through point *o* parallel to any one of the bounding lines of the plane by the procedure just explained. An infinite number of lines may be drawn through a point parallel to a plane. A 1-auxiliary view showing the line projection of the plane and the respective projection of the line would show the line and the plane parallel.

15-25. Plane parallel to a plane. Two planes are parallel when two intersecting lines in one are parallel to two intersecting lines in the other. At

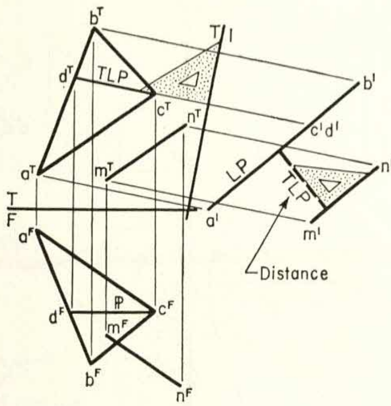


Fig. 15-27. Distance between parallel line and plane.

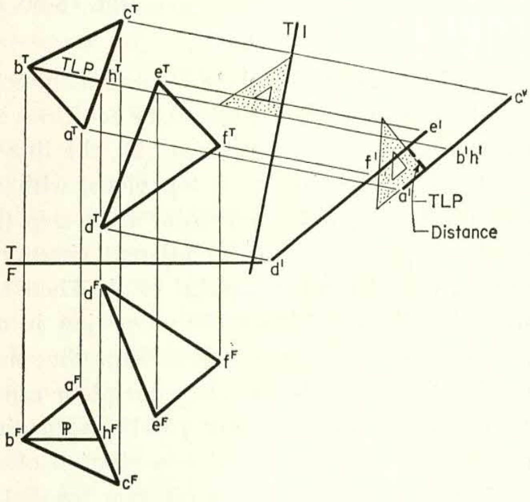


Fig. 15-28. Distance between parallel planes.

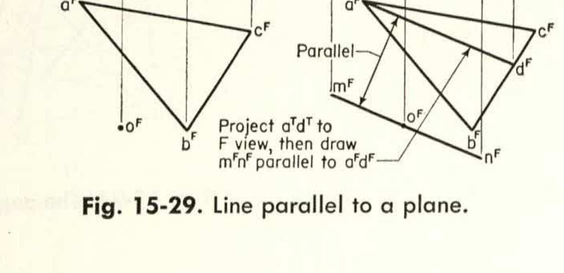


Fig. 15-29. Line parallel to a plane.

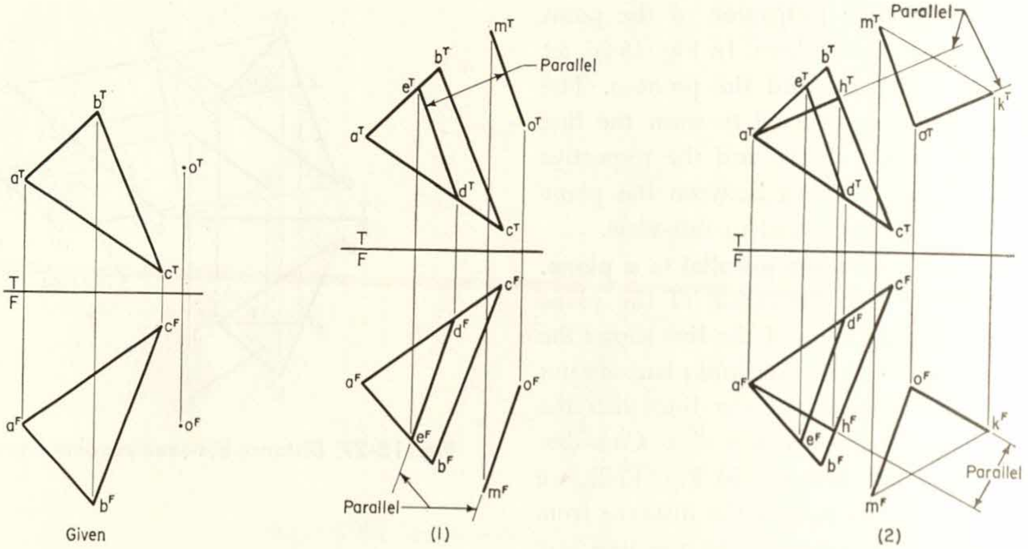


Fig. 15-30. Plane parallel to a plane.

the left of Fig. 15-30, the plane *abc* and the point *o* through which the other plane is to be drawn are shown in adjacent views. In step (1), the line *de* was placed in the front and top views, with *mo* drawn through *o* parallel to the line *de*. In step (2), line *ah* was placed in the two adjacent views with line *ko* drawn through *o* parallel to *ah*. These two intersecting lines (which need not project in any view as true-length projections) form the plane *kom* that is parallel to *abc*. Only one plane can be drawn through a given point parallel to a given plane. A view showing the line projection of *abc* would show *kom* as a line projection parallel to *abc*.

15-26. The angle a line makes with a plane. The angle a line makes with a plane is seen in the view that shows the true-length projection of the line and the respective edge or line projection of the plane. In Fig. 15-31, the line *mn* and the plane *abc* are given at the left. The first step (1) in the procedure is to secure the view that shows the true shape of the plane with the respective projection of the line. This is shown in the 2-auxiliary of step (1). The next step is to construct a 3-auxiliary which shows the line in its true-length projection. In this view, the plane automatically projects as a line projection [shown at far right in step (2)], thus revealing the required angle. To save the drawing of the 3-auxiliary, the line *mn* can be revolved parallel to the 1-2 reference line and its true-length projection shown in the 1-auxiliary, where the plane appears as a line projection. The angle

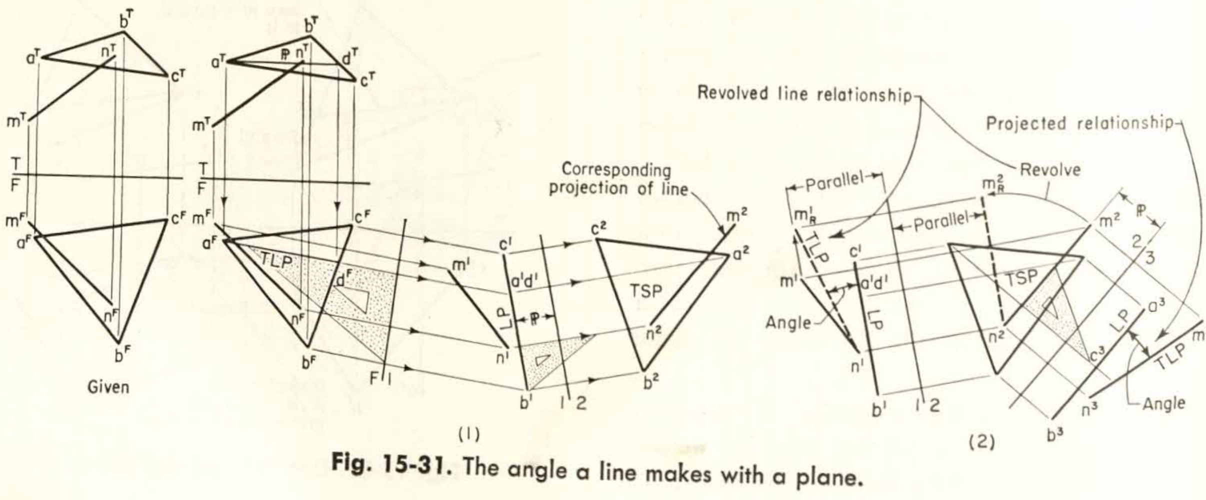


Fig. 15-31. The angle a line makes with a plane.

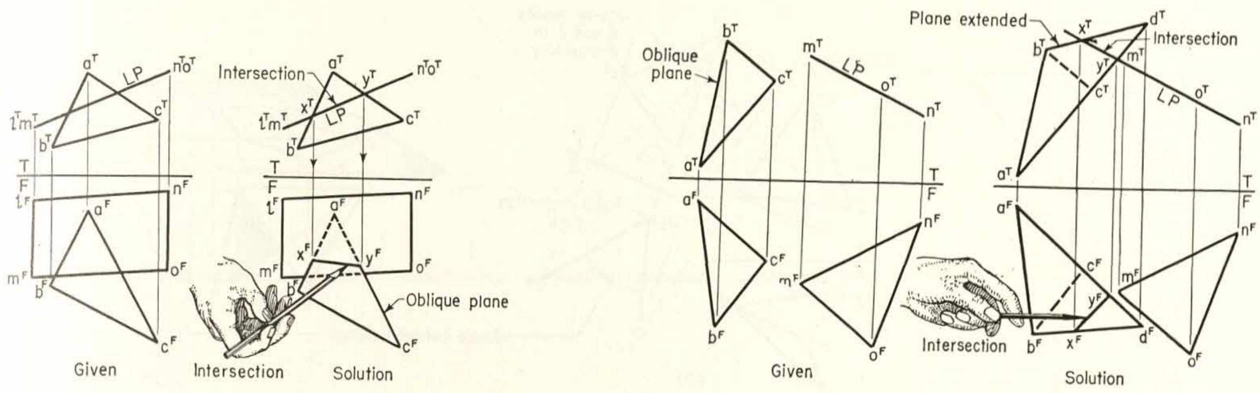


Fig. 15-32. Line of intersection of planes.

can be measured in this view, also. See Secs. 9-10 and 15-46 for true-length projection by revolution.

15-27. Line of intersection of two planes. A view showing the line projection or edge of one plane indicates it as its intersection with other planes. If one plane appears in its line projection and another lies obliquely in a given view, their line of intersection actually lies in the line projection and it may be projected to an adjacent view as shown at the left in Fig. 15-32. If necessary, the oblique plane may be extended to permit the intersection being shown in both adjacent views (at right in Fig. 15-32.

When both planes appear obliquely in the given adjacent views, a line-projecting plane (a cutting plane appearing as an edge in the view of origin) intersecting the given planes *abc* and *def* may be passed in one view [front view of pictorial and Fig. 15-33 (1)]. The intersections *xy* and *mn* of the line-projecting plane with the given planes are then projected to the adjacent (top) view. If these intersections *xy* and *mn* (of the line-projecting plane with the given planes) are not parallel to each other in the top view, they will intersect at a point *o* common to (and thus lie on the line of intersection of) the given planes. This point *o* may be projected to (it lies in the line-projecting plane in) the adjacent (front) view. Repeating the procedure (the line-projecting plane may be passed in any suitable direction in either adjacent view) establishes a second point *y* through which the line of intersection *oy* of the given planes may now be drawn. A third point would determine the accuracy of the draftsman's work.

Any number of lines may be drawn parallel to two oblique planes. However, through a given point only one line can be drawn parallel to two oblique planes. Any line parallel to two oblique planes lies parallel to their line of intersection.

15-28. Angle between planes. The view that shows the point projection of their line of intersection shows the angle between planes. In Fig.

A line projecting plane may be passed perpendicular to any view of projection, either parallel to the reference line or not

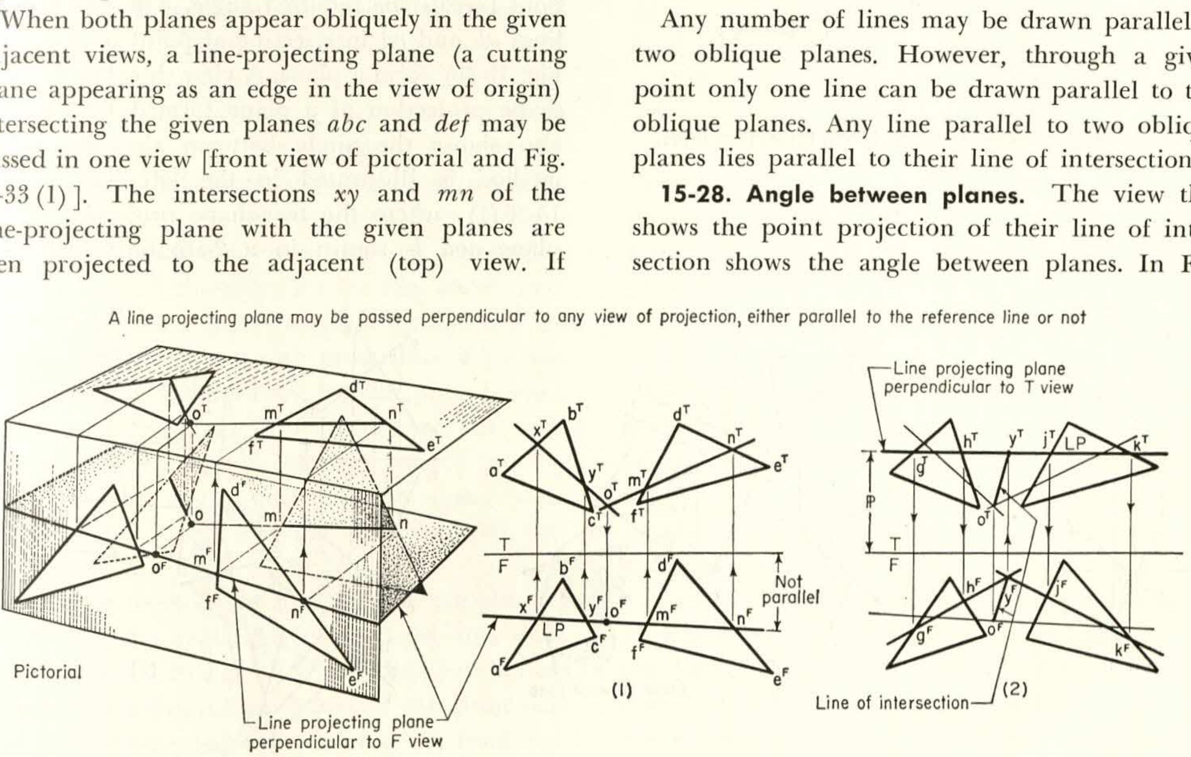

Pictorial
Line projecting plane perpendicular to F view
(1)
Not parallel
LP
T
F
Line projecting plane perpendicular to T view
Line of intersection
(2)

Fig. 15-33. Line of intersection of planes.

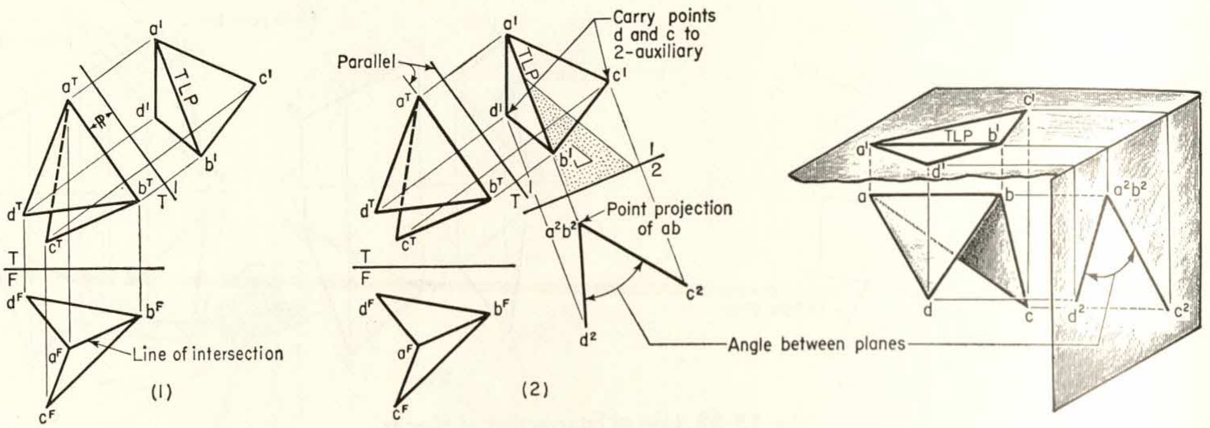


Fig. 15-34. Angle between planes.

15-34, step (1), the true-length projection of the line of intersection *ab* of the two given planes and a point *c* and *d* on each plane have been projected to a 1-auxiliary. Step (2) shows the point projection of *ab* with respective projections of points *c* and *d* in the 2-auxiliary, where the angle between the planes may be measured. In this problem, it is always necessary to carry at least one other point of each plane to the view showing the line of intersection (with its points) as a point projection.

15-29. Angle between intersecting lines. The view showing the given lines as true-length projections reveals the required angle. The two oblique lines *ab* and *cd* intersecting at point *o* (at left in Fig. 15-35) form a plane. A view showing the true-shape projection of a plane formed by the lines also shows the angle between the lines. This method is illustrated in the left half of Fig. 15-36 (1), where the true-shape projection of the plane *aod* is shown in a 2-auxiliary. The line

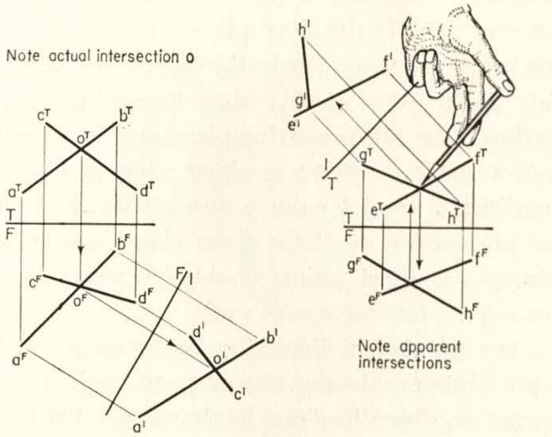


Fig. 15-35. Intersecting lines. Nonintersecting lines.

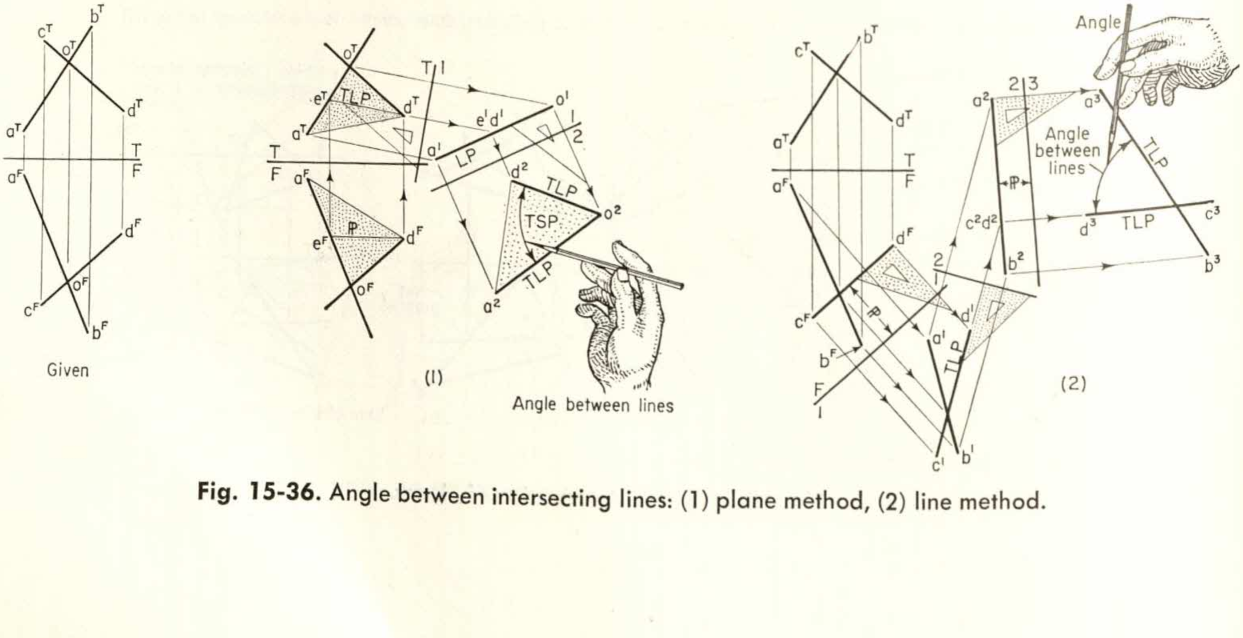


Fig. 15-36. Angle between intersecting lines: (1) plane method, (2) line method.

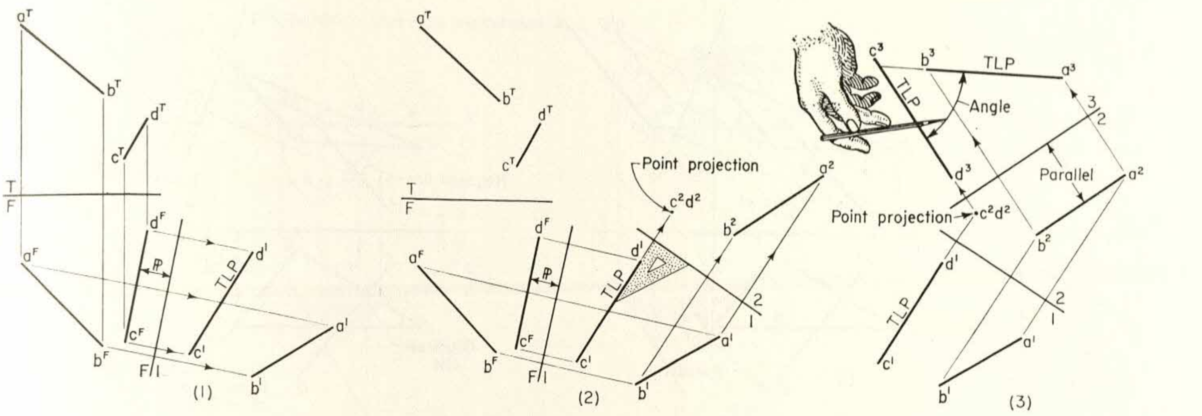


Fig. 15-37. Angle between nonintersecting lines. Line method.

method for obtaining the solution is explained in the right portion of Fig. 15-36. In (2), the line method, the true-length projection of *cd* and the respective projection of *ab* are shown first in the 1-auxiliary. Next, the point projection of *cd* with the respective projection of *ab* is secured in a 2-auxiliary. The true-length projection of *ab* is shown in an additional auxiliary, where the point projection of *cd* in the 2-auxiliary automatically appears as a true-length projection in the additional auxiliary and reveals the angle between the two lines.

15-30. Angle between nonintersecting lines. A view showing the lines as true-length projections reveals the required angle. At the right in Fig. 15-35, the two oblique lines *ef* and *gh* do not intersect and thus do not form a plane. To find the angle one line makes with the other, it is necessary to construct the view showing both lines as true-length projections. The steps followed are similar to those used in the solutions for Fig. 15-36. The problem is worked out by the line method in Fig. 15-37, where the true-length projection of *cd* has been secured in a 1-auxiliary (1), the point projection of *cd* is next shown in the 2-auxiliary (2), and the true-length projection of *ab* is secured in a 3-auxiliary (3), where *cd* automatically appears as a true-length projection and the angle between the lines may be measured.

The plane method (1) of Fig. 15-36 can also be used to find the angle between oblique lines that do not intersect. In Fig. 15-37, if a line parallel to *cd* and intersecting *ab* is drawn in the principal views and the true-shape projection of the resulting plane is secured, the angle between *ab* and the line drawn parallel to *cd* would be similar to the angle between *ab* and *cd*.

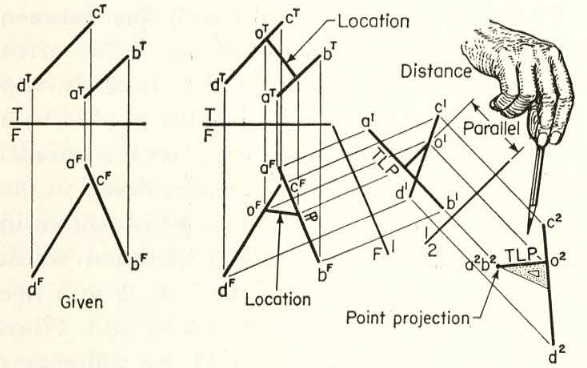


Fig. 15-38. Distance between lines.

15-31. The distance between lines. The distance between parallel lines is seen in the view where both appear as point projections. (See Sec. 15-14.) The distance between nonparallel nonintersecting lines is seen in the view which shows the point projection of one line with the respective projection of the other. This distance is a common perpendicular to both lines. The oblique lines *ab* and *cd* are given at the left in Fig. 15-38. The first step (at right) shows the true-length projection of *ab* with the respective projection of *cd* in the 1-auxiliary. The next step, seen in the 2-auxiliary, shows the required solution where the distance appears as a line drawn perpendicular to *cd* through the point projection of *ab*. The distance in this view is a true-length projection and is perpendicular to both lines *ab* and *cd*. When projected back to the 1-auxiliary, it is drawn through point *o* on *cd* to line *ab* parallel to the 1-2 reference line. The distance may now be projected back to the principal views in the usual manner.

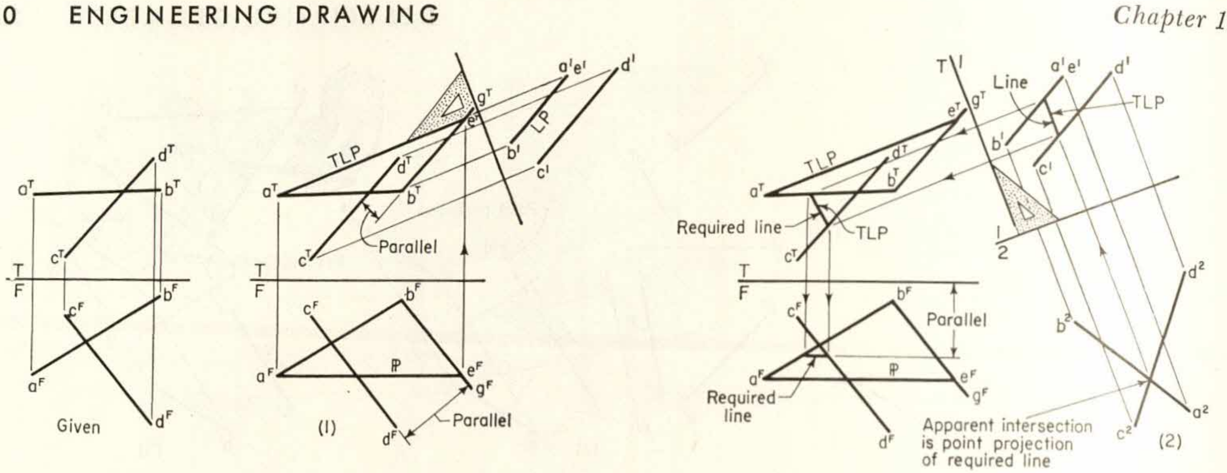


Fig. 15-39. Shortest horizontal (level) line between two nonintersecting lines.

15-32. Shortest horizontal (level) line between two nonintersecting oblique lines. The given lines are shown at the left in Fig. 15-39. In step (1), line *bg* has been passed parallel to *cd* in both principal views, to construct the plane *abg* parallel to line *cd*. The parallel *ae* has been drawn in the front view and its true-length projection shown in the top view. The 1-auxiliary elevation which shows the plane containing the line *ab* as a line projection also shows line *cd* parallel to it. When drawn in, the required horizontal line will appear parallel to the *T*-1 reference line in this 1-auxiliary. The additional 2-auxiliary elevation in (2) (drawn at right angles to the 1-auxiliary and thus actually another elevation view) shows the apparent intersection of the two lines *ab* and *cd*. This apparent intersection is the actual position of the point projection of the required horizontal line, which can now be projected back to the other views in the usual manner.

15-33. Line through a point intersecting two given lines. The desired line can be located in the view that shows one given line as a point projection with the respective projections of the given point and the other given line. The two lines *ab* and *cd* and the point *o* are given in adjacent views at the left of Fig. 15-40. In (1), the true-length projection of line *cd* and the respective projections of *ab* and the point *o* have been located in a 1-auxiliary. In (2), the point projection of *cd* was secured in the 2-auxiliary, and from it the required line has been drawn through the respective projection of point *o* intersecting line *ab* at *y*. The line may now be projected to the other views through *o* in the usual manner.

15-34. Perpendicular lines. For the purpose of demonstrating the conditions that exist when perpendicular lines occur on the drawing sheet, the adjacent views of a wheel and its spokes, attached to an axle placed perpendicular to it, are shown at the left in Fig. 15-41. Each spoke in the plane of the wheel is perpendicular to the axle. In space, then, any line representing one of the spokes, when revolved on its hub at *a*, would always remain per-

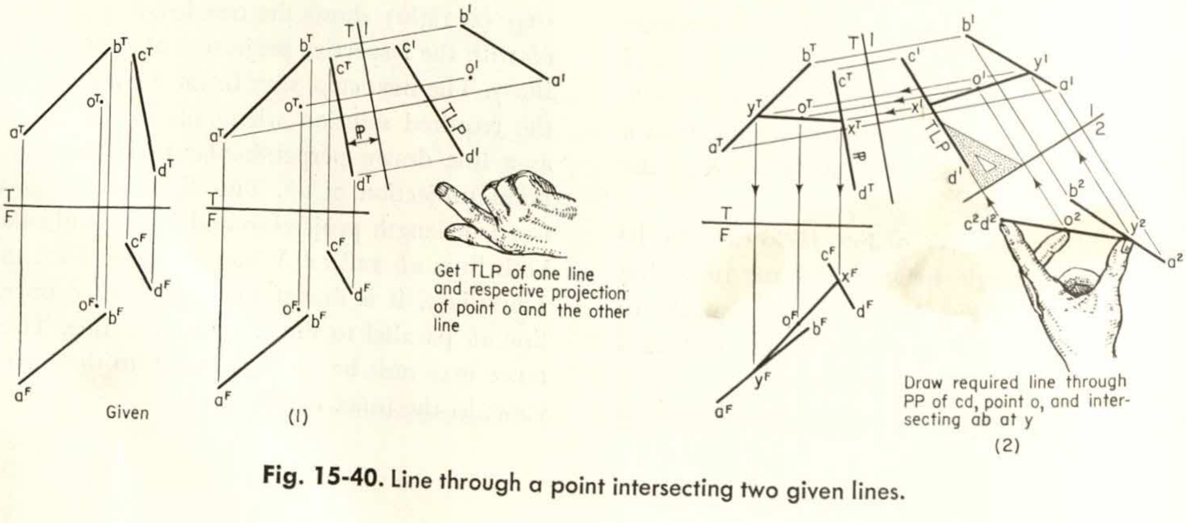

Given
(1)
TLP
Get TLP of one line and respective projection of point o and the other line
TLP
Draw required line through PP of cd, point o, and intersecting ab at y
(2)

Fig. 15-40. Line through a point intersecting two given lines.

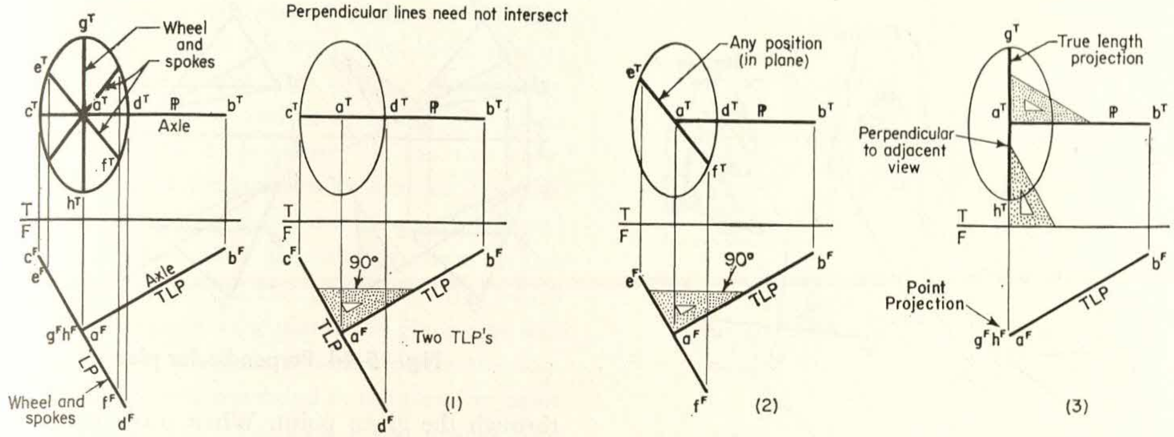


Fig. 15-41. Perpendicular lines.

pendicular to the axle *ab,* regardless of its final stationary position. From a study of this simple phenomenon, we may establish the conditions whereby perpendicular lines can always be recognized on the drawing sheet. If two lines project in their true length and make an angle of 90° with each other in any view of projection [see front view of Fig. 15-41 (1)], they are perpendicular in space and will appear parallel to the reference line in the view (top) from which they were projected. If a view presents two lines making an angle of 90° with each other and one line appears in its true-length projection, the lines are perpendicular in space [see front view of (2)], and in the view from which they were projected (top) the true-length projection will lie parallel to the reference line and the other line may take any position. When one line appears as a point projection and the other as a true-length projection, as seen in the front view of (3), the lines are perpendicular in space, and in the view from which they were projected (top) the point projection will show as a line perpendicular to the reference line while the true-length projection lies parallel to the reference line. From the preceding discussion and a review of Fig. 15-41, it is obvious that any number of lines may be passed through any given point perpendicular to a line, only one plane can be passed through a given point perpendicular to a given line, and perpendicular lines need not intersect one another. Keeping these statements in mind and recognizing the particular conditions indicating perpendicular lines when they occur in views of projection will enable you better to understand the space relationships of the lines you are working with and to solve problems where understanding these principles or constructions is necessary to the solution.

15-35. Line (through a point) perpendicular to a plane. A line is perpendicular to a plane when it is perpendicular to two intersecting lines in the plane. The plane *abc* and the point *o* are given at the left in Fig. 15-42. In (1), the line *dc* has been drawn parallel to the reference line in the

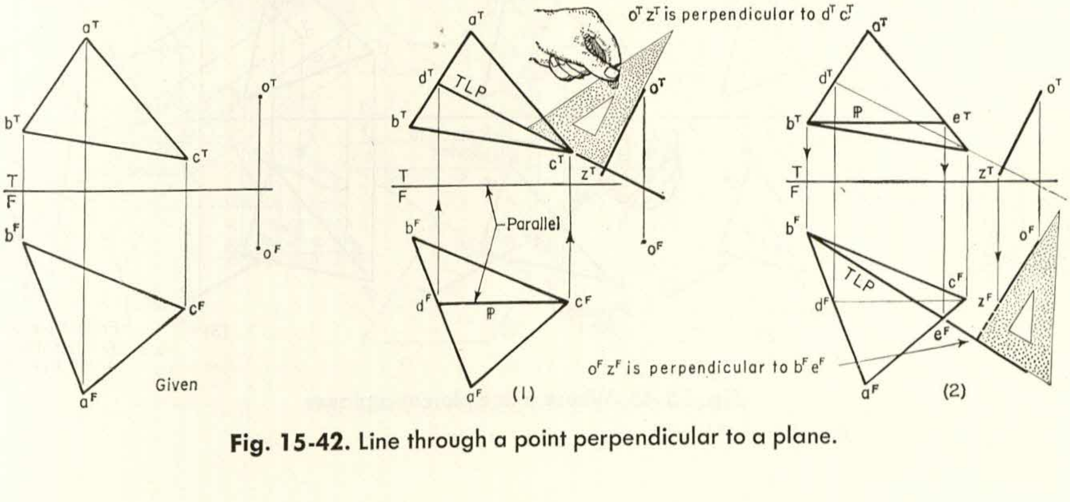


Fig. 15-42. Line through a point perpendicular to a plane.

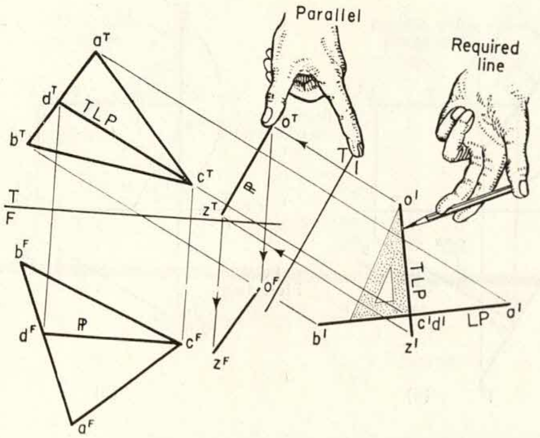


Fig. 15-43. Line perpendicular to a plane.

front view and its true-length projection located in the top view. The direction of the required line in this view is fixed by drawing it through *o* perpendicular to *dc*. In (2), a second parallel *be* has been drawn in the top view and shown in its true-length projection in the front view [see Fig. 15-42 (2)]. The direction of the required line is fixed in this view by constructing it through *o* perpendicular to *be*. The limiting points *o* or *z* of the line may be extended to suit the draftsman's needs. Only one line can be drawn through a given point perpendicular to a plane.

An extra view method is shown in Fig. 15-43. The line-projection or edge view of the plane is secured in a 1-auxiliary. The required line is constructed perpendicular to the line projection

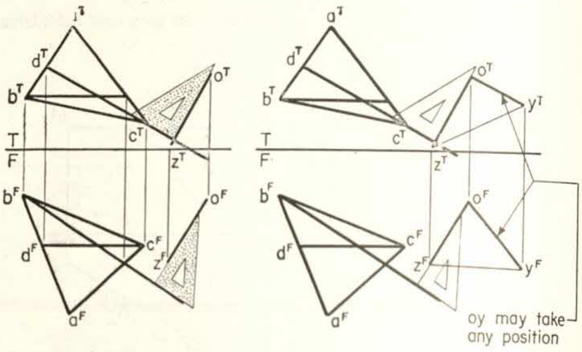


Fig. 15-44. Perpendicular planes.

through the given point. When projected back to the principal views, *oz* will appear parallel to the *T*-1 reference line in the top view since it is a true-length projection in the 1-auxiliary. The auxiliary also reveals the piercing point of the line with the plane, which if desired can be projected to its position on the line (extended if necessary) in the principal views.

15-36. Perpendicular planes. Two planes are perpendicular to each other when a line in one plane is perpendicular to two intersecting lines in the other plane. In Fig. 15-44 (at left), the line *oz* has been constructed perpendicular to the plane *abc* according to the method described in Sec. 15-35. To form the plane of the intersecting lines *oyz* (at right), the line *oy* is placed at random since any number of planes may be constructed through a point perpendicular to a given plane. A different position selected for point *y* of line *oy* would determine another plane through point *o* perpendicular to plane *abc*.

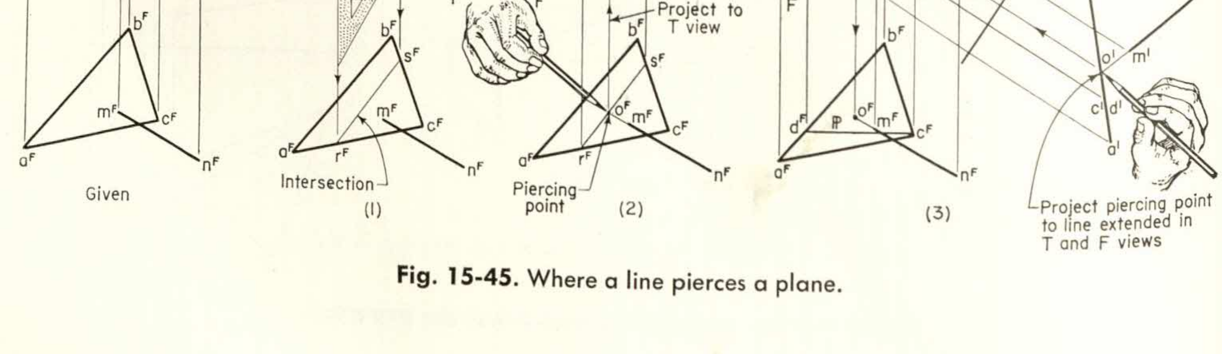


Fig. 15-45. Where a line pierces a plane.

15-37. Where a line pierces a plane. The line and plane are given at the left in Fig. 15-45. In (1), a line-projecting plane (or cutting plane) containing the line *mn* and intersecting the given plane in the line *rs* is passed in the top view. Then the line of intersection *rs* between the line-projecting plane and the given plane is projected to the front view. Since the intersection *rs* in this view is not parallel to the given line *mn*, which lies in the line-projecting plane, the given line will pierce the given plane in this line of intersection. In (2), *mn* has been extended to the piercing point *o* in the front view. The point *o* was projected to the line *mn* extended in the top view. Reversing the procedure, by passing the line-projecting plane containing the given line in the front view and finding the piercing point in the top view, the accuracy of the work performed would be proved. See also Secs. 16-1 and 16-2.

The piercing point would also be revealed in a 1-auxiliary view showing the given plane as a line projection and the respective projection of the given line [see Fig. 15-45 (3)].

15-38. Where a line pierces a sphere. The piercing points of a line with a sphere are revealed in a view which shows the true-shape projection of a plane that contains the line and cuts a circle through the sphere. The sphere with its center at *c* and the line *ab* are given at the left of Fig. 15-46. At the right in the front view, a line-projecting cutting plane has been passed, containing the line *ab* and cutting a circle through the sphere. The 1-auxiliary was constructed parallel to the given line

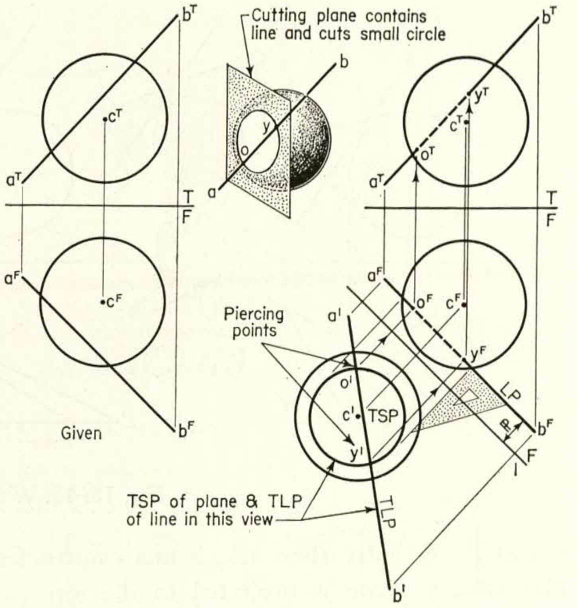


Fig. 15-46. Where a line pierces a sphere.

and the line projection of the cutting plane that contains the line. This produced a true-shape projection view of the given line and the cutting plane, with the resulting cut circle. The piercing points *o* and *y* are located in this view at the intersections of the line *ab* with the circumference of the cut circle. The points *o* and *y* are projected to the line in the given views in the usual manner.

15-39. Where a line pierces a cylinder. The line and the cylinder are given at the left in Fig. 15-47. In the front view (elevation) of (1), a cutting plane *cde* containing the line *ab*, cutting the base (line *ce* lying in base) and parallel to the

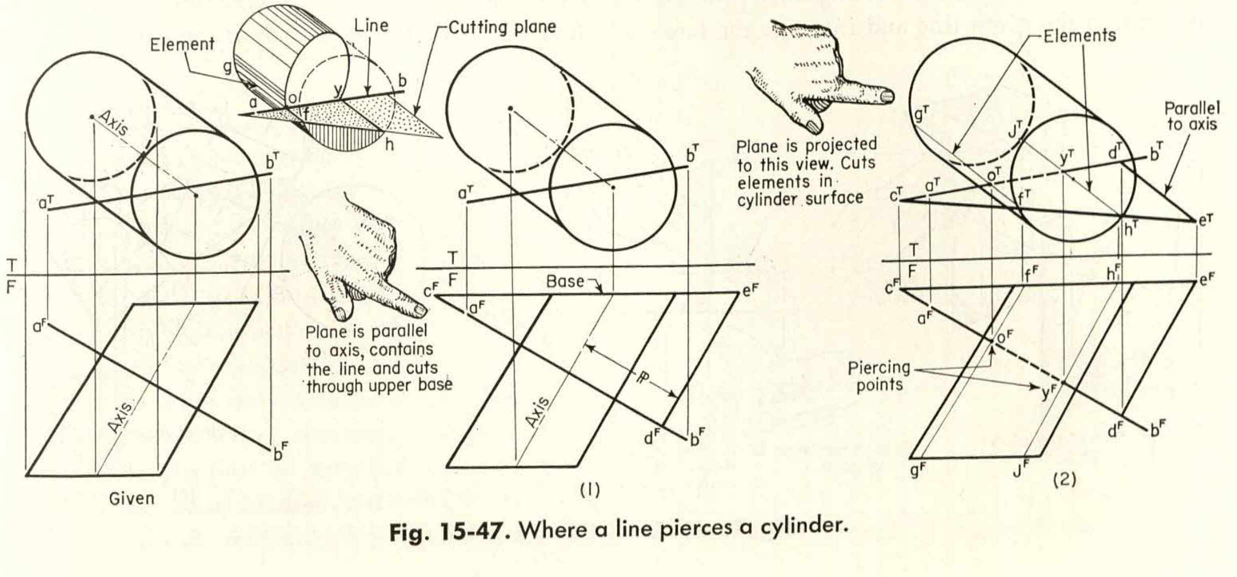


Fig. 15-47. Where a line pierces a cylinder.

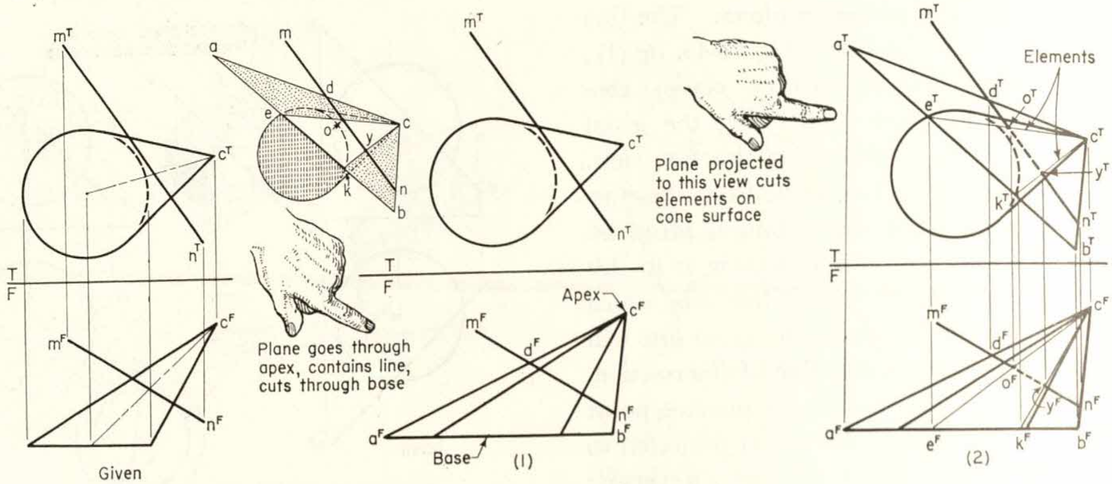


Fig. 15-48. Where a line pierces a cone.

axis of the cylinder (line *de*), is first constructed. This cutting plane is projected to the top (adjacent) view in (2), where point *c* is on the line *ab* extended, *de* is drawn through point *d* parallel to the axis of the cylinder, and *e* is located on its projector from the front view. Line *ce* in the base locates the points *f* and *h*, which are the extremities of the elements the cutting plane produces on the lateral surface of the cylinder. Since the line and the elements lie in the cutting plane, the intersections (*o* and *y*) of the given line with the elements are the desired piercing points. The elements may be projected to the front view, where their intersections with the line can be seen by inspection or the points alone may be projected from their positions in the top view to the line in the front view.

15-40. Where a line pierces a cone. The cone and the line are given at the left in Fig. 15-48. The cutting plane employed in solving this problem must contain the given line and intersect the base-plane and the apex of the cone. In the front view in (1), the constructed cutting plane *abc* contains the line *mn* and cuts through the base (line *ab* lying in the base) and the apex (*c*) of the cone. This plane is projected to the top view in (2), where the projections of points *d* and *n* of the line, the apex of the cone *c*, and the projection of line *ab* from the front view control the construction of the cutting plane in the top view. In the top view, line *ab* intersecting the circumference of the base produces points *e* and *k*. These are the extremities of elements *ec* and *kc* lying on the surface of the cone, which are produced by the cutting plane that also contains the line *mn*. The intersections of the given line *mn* with the elements produce points *o* and *y*, the desired piercing points. These may be projected to the line *mn* in the front view, or the elements may be projected from the top to the front view, where the intersections lying on the line will then be evident by inspection.

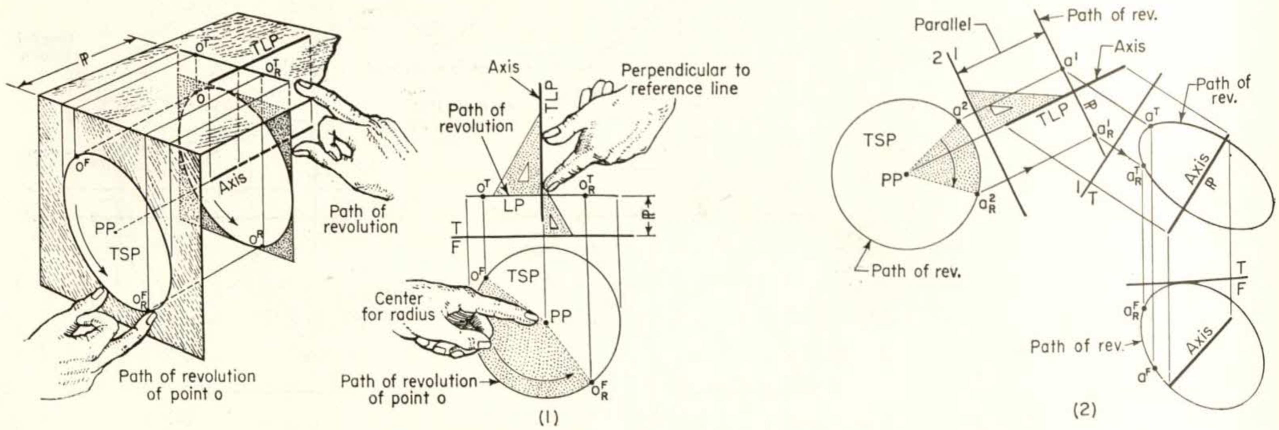


Fig. 15-49. Revolution of a point.

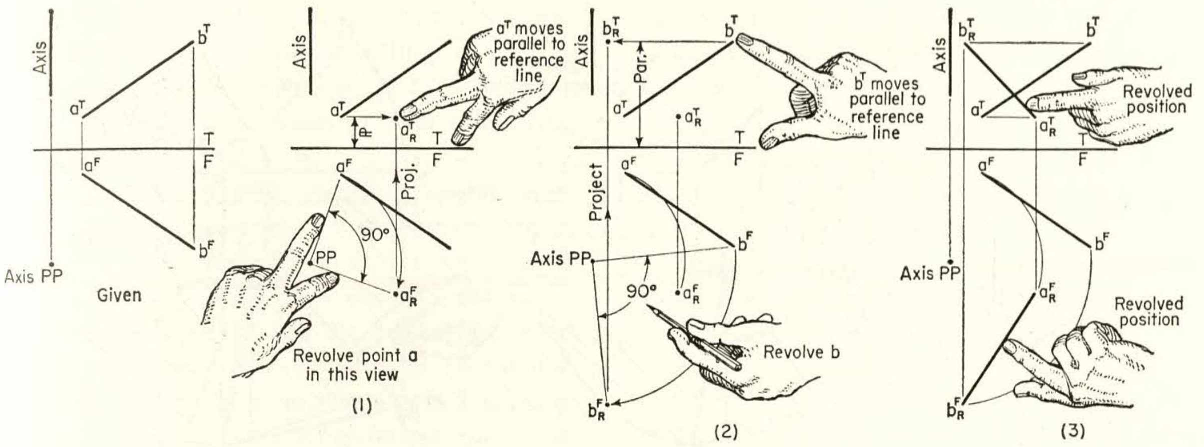


Fig. 15-50. Revolution of a line.

15-41. Revolution. Although revolution is not too practical a method to employ in actual drafting practice, it is helpful to understand the application of its fundamentals so that you can safely rely on your own judgment when using it, alone or in combination with the direct or projected relationship procedures explained in the preceding sections. Many problems may be more readily solved by revolution alone or by combining it with other methods, and in some instances it may be used as a check for the accuracy of other work.

15-42. Revolution of a point. A point is always revolved about an actual or implied axis. Studying the pictorial and Fig. 15-49 (1) together, we note that a point is revolved in the view in which the axis appears as a point projection. The point may be revolved clockwise or counterclockwise, and its path in this view is always a circle appearing in its true-shape projection. In its adjacent view, the path of revolution along which the point moves is an edge or line projection parallel to the reference line, with the axis appearing as a true-length projection lying perpendicular to this reference line. If a problem presents itself where the above-mentioned conditions do not exist in the given views, newly constructed views [see Fig. 15-49 (2)], one of which shows the actual or implied axis of revolution as a point projection, with the adjacent view showing this axis as a true-length projection, must be prepared before starting the revolving procedure. After the revolved position of a point has been found in each of the newly prepared views, its revolved position is projected to the original views in the usual manner by scaling its distance from the proper reference line of one view and locating the point on its projector in the related view. The path of revolution in the original views will appear as an ellipse. However, it is not always necessary to show this ellipse on the drawing sheet, nor is it always required in order to locate the revolved position of the point in these views.

15-43. Revolving a line. The technique applied in revolving a point applies also in revolving a line. In this case, the procedure is simply that of revolving two points about the same axis, with each point, however, revolving the same number of degrees along its own individual path of revolution. The line *ab* given at the left in Fig. 15-50 is to be revolved clockwise 90° about the given axis. At (1), the point *a* has been revolved the required 90° in the front view, and its revolved position is shown in the top view (where the point *a* moves in a path parallel to the reference line). In (2), the point *b* has also been revolved 90° in the front view, and its revolved position (where it moves parallel to the reference line) is shown in the top view. At this point, you should realize that when performing the act of revolution you are actually revolving everything (all points) appearing in a view of projection about an actual or imaginary axis, and these points, while revolving through the same number of degrees, move in their own paths of revolution. The revolved position of the line *ab* is shown in (3).

15-44. Revolving a plane. Revolving a plane surface or the average geometric solid requires only the revolution of the points at the intersections of the lines forming the edges of the surfaces. The rules set forth in the preceding sections should be applied in performing this operation.

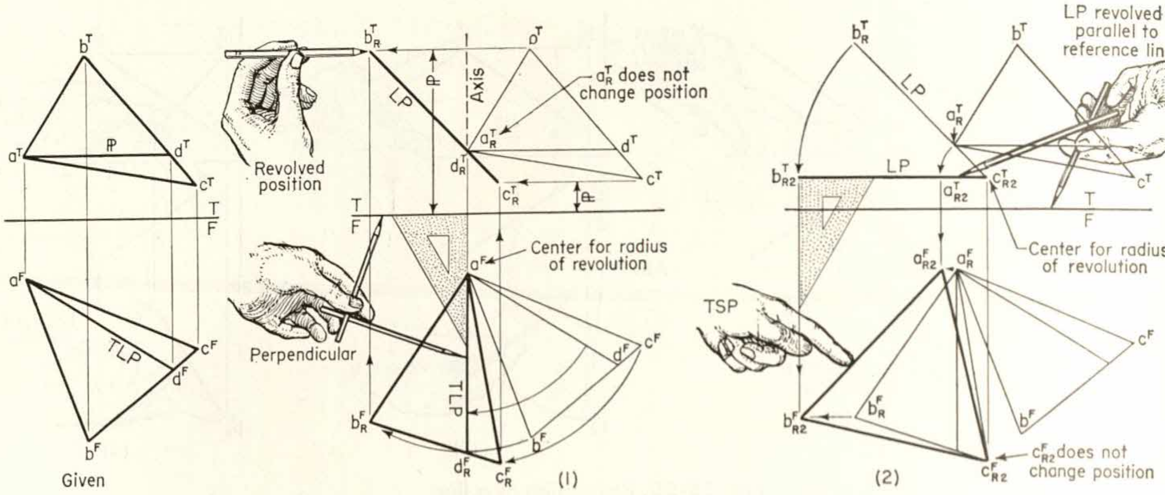
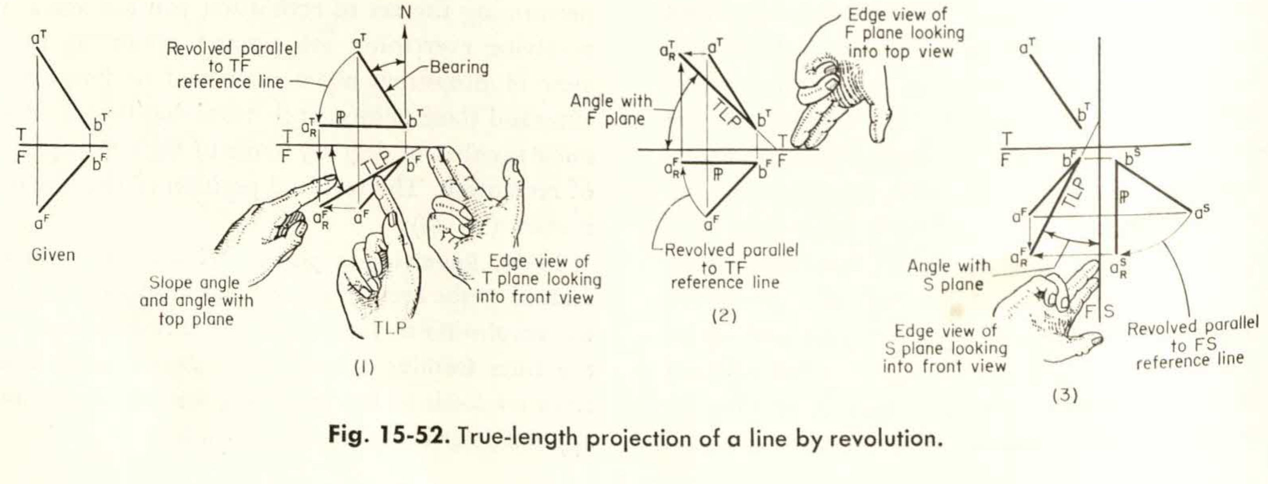


Fig. 15-51. True shape of plane by revolution.

15-45. True shape of plane by revolution. The true shape of a plane may be secured by double revolution, that is, performing the act of revolving all the points in one view and then revolving them in the adjacent view. The given plane appears at the left in Fig. 15-51. The parallel *ad* placed in the top view and projecting as a true-length projection in the front view starts the solution procedure. In (1), using *a* as the implied point projection of the axis of rotation, the plane *abc* was revolved in the front view to show *ad* perpendicular to the reference line. The plane in this revolved position was then projected to the adjacent top view, where the revolved position of line *ad* appears as a point projection and the plane *abc* as a line projection or edge. (Point *a* itself has been revolved but does not change in location in either view.) In (2), the line projection of the plane *abc* appearing in the top view was revolved parallel to the reference line, using point *c* (which does not change location in either view) as the implied axis of rotation. This revolved position of the line projection was projected to the front view, where the location of the revolved points *abc* describes the plane in its true-shape projection.

15-46. True-length projection of a line by revolution. If a line is revolved parallel to a plane of projection (the reference line for that view), it will appear in its true-length projection in the adjacent view. The line we shall work with is *ab*, shown at the left in Fig. 15-52. In (1), the line was revolved to the position where it appears parallel to the reference line in the top view. Its revolved position projected to the front view shows the line in its true-length projection and also the angle the line makes with the horizontal, or top, plane. In (2), the line was revolved parallel to the reference line in the front view and its revolved position projected to the top view, where the true-length projection and the angle between the line and the



a^T
b^T
T
F
b^F
a^F
Given
N
Revolved parallel to TF reference line
a^T
Bearing
a_R^T
FP
b^T
T
F
TLP
b^F
a_R^F
a^F
Slope angle and angle with top plane
Edge view of T plane looking into front view
TLP
(1)
Edge view of F plane looking into top view
a_R^T
a^T
Angle with F plane
TLP
b^T
T
F
a_R^F
FP
b^F
a^F
Revolved parallel to TF reference line
(2)
a^T
b^T
T
F
b^F
b^S
TLP
FP
a^F
a^S
Angle with S plane
a_R^F
a_R^S
F S
Edge view of S plane looking into front view
Revolved parallel to FS reference line
(3)

Fig. 15-52. True-length projection of a line by revolution.

front plane may also be seen. In (3), the line was revolved parallel to the reference line in the side view. Its true-length projection in the front view also reveals the angle it makes with the side plane. See also Sec. 9-10.

15.47. A line making specified angles with given planes of projection. The required line is the element at the intersection of two cones whose slant heights are equal. This element makes one of the specified angles with the base of one cone and the other specified angle with the base of the other cone. The line we are seeking is 2 in. long and makes an angle of 45° with the horizontal and 30° with the front plane. The solution starts in the front view in Fig. 15-53 (1), where the point *o* is the apex of cone *A,* through which the extreme element *eo* in true-length projection is drawn, making one of the specified angles, 45°, with the horizontal plane. In the top view, the base of the cone appears as a circle, and the extreme element *eo* lies parallel to the reference line. In step (2), top view, the cone *B* is drawn with *o* as its apex, and the extreme element *ko* in true-length projection makes the other specified angle, 30°, with the front plane. In the front view, the base of cone *B* appears as a circle, and the extreme element *ko* lies parallel to the reference line. Since the slant height of both cones is equal, their bases will intersect in both top and front views at point *r*. A line drawn through the points *r* and *o* is an element common to both cones *A* and *B* and makes the specified angles, 45° with the horizontal and 30° with the front plane. There are eight positions possible for this line.

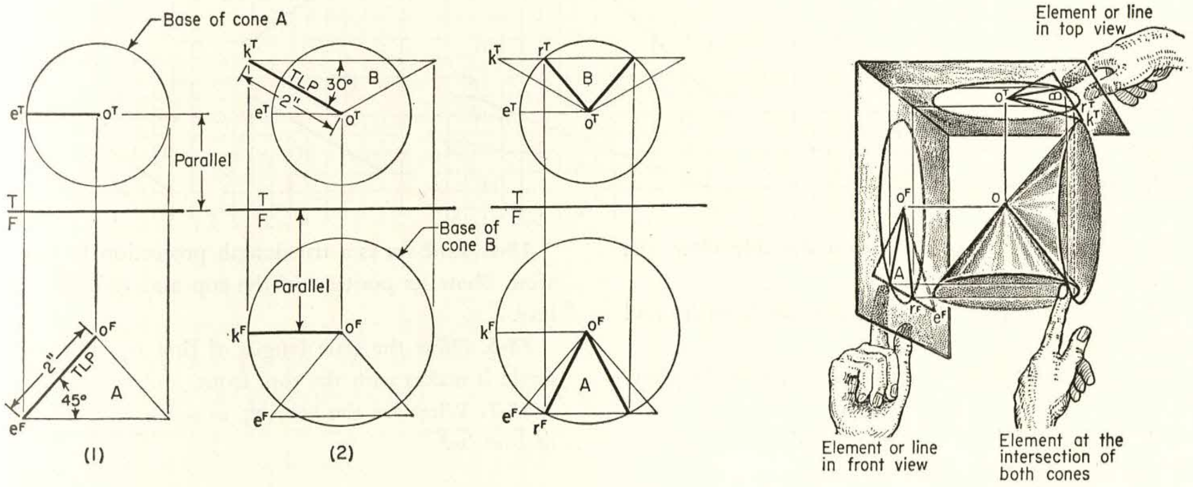


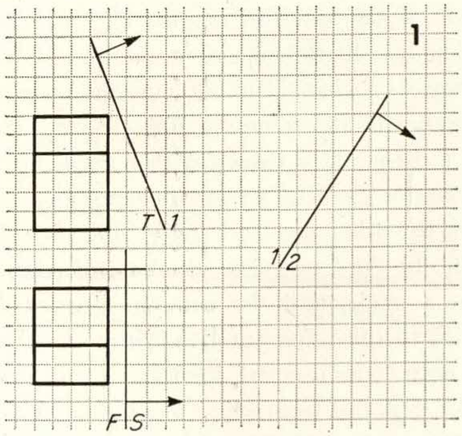
Fig. 15-53. Line making specified angles with given planes of projection.

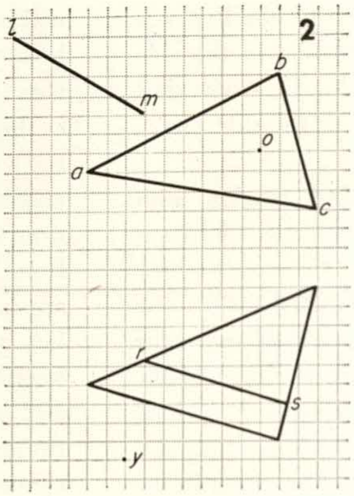
PROBLEMS

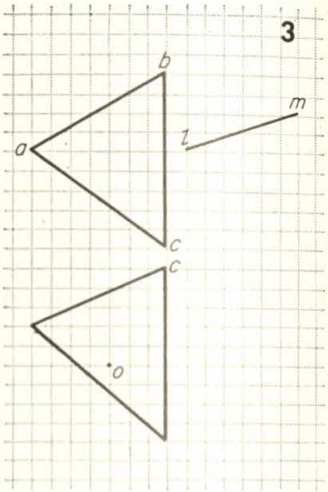
The following are intended to give practice in solving most problems in descriptive geometry that confront the draftsman, designer, and engineer. All the drawing work for each problem can be done in an area of approximately 4 by 5 in., or a half portion of the standard 8½- by 11-in. drawing sheet.

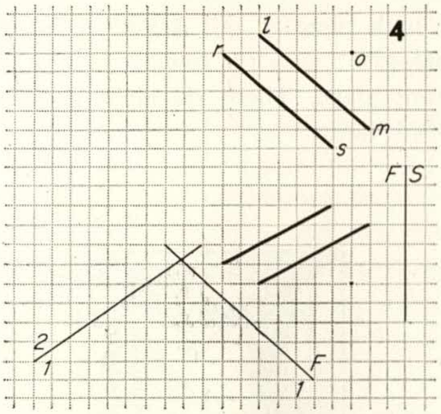
Fix your 8½- by 11-in. eight-squares-to-the-inch cross-section paper vertically on the drawing board. (Instruments must be used for all work.) Draw a ½-in. border all around. Draw a line dividing the sheet into an upper and a lower half. Reconstruct in these halves (in the approximate center or where your judgment in projecting procedure seems to indicate) the given data for each problem, using the intersections on the ⅛-in. squares as guides for locating the points, lines, and planes. (By placing the ⅛-in. cross-section paper underneath it to serve as a guide, the work may also be done on 8½- by 11-in. tracing paper if desired.) Your finished drawing must show all reference lines (reference lines must appear between all views), points, lines, and planes drawn in with reasonably heavy lines and properly and completely labeled in all views of projection. The projectors of the points are to be drawn very thinly and lightly, and they must also be shown in the final drawing.

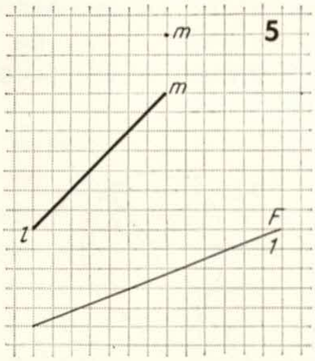
Keep a keenly sharpened point on the pencil at all times, for extreme accuracy is necessary to ensure precise solutions.

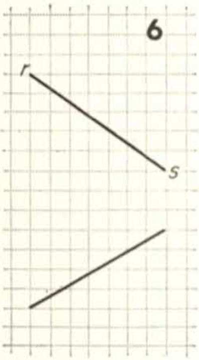


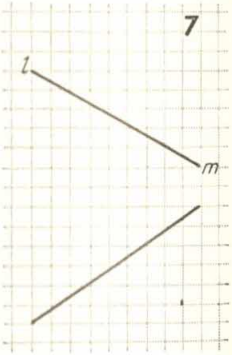












15-1. Project the given solid into the side view, the 1-auxiliary, and the 2-auxiliary.

15-2. Locate the points *o* and *y* and the lines *lm* and *rs* in the plane *abc*.

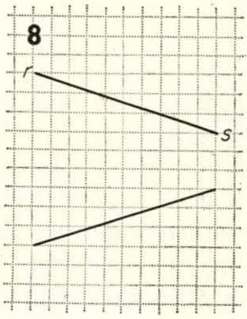
15-3. Locate the point *o* and the line *lm* in the plane *abc*.

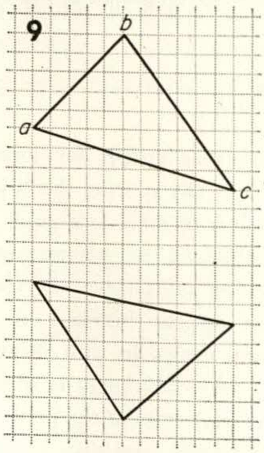
15-4. Project the lines *lm* and *rs* and point *o* to the side, and then draw the auxiliary views.

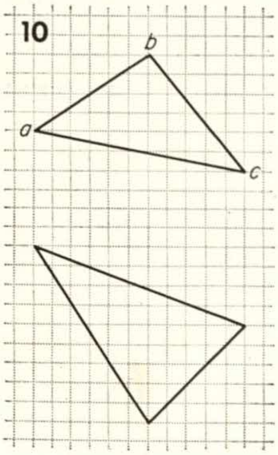
15-5. Line *lm* is a true-length projection in the front view. Show its position in the top and indicated auxiliary.

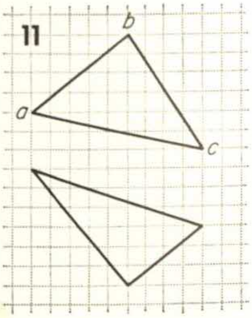
15-6. Show the true length of line *rs*, and label the angle it makes with the top, front, and side planes.

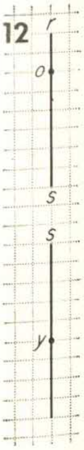
15-7. What are the bearing, azimuth, and slope angle of line *lm?*











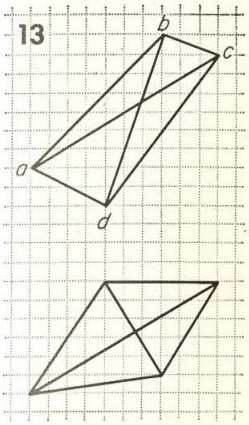
15-8. Find the point projection of line *rs.*

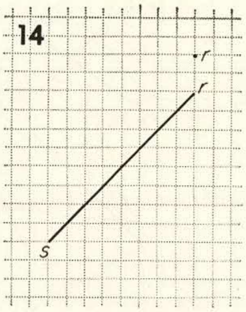
15-9. Find the angle plane *abc* makes with the front plane.

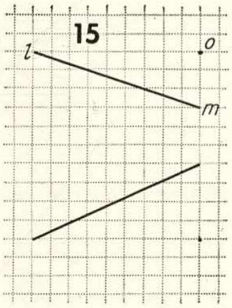
15-10. Show the dip angle of plane *abc.*

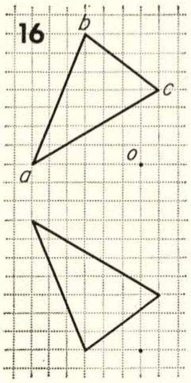
15-11. Show the true-shape projection of plane *abc* by projections from the top and front views. Label the dip angle and the angle the plane makes with the front view.

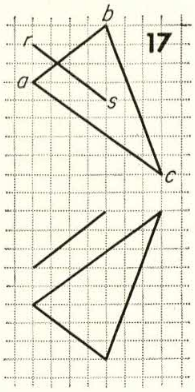
15-12. Locate the point *o* in the front view and point *y* in the top view of line *rs.*











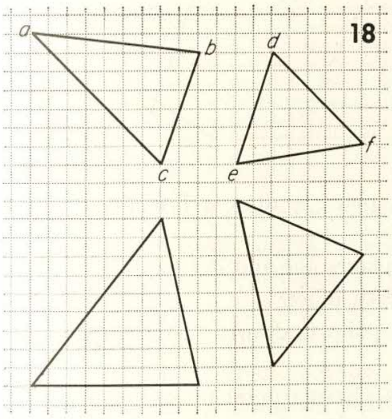
15-13. Redraw the polyhedron *abcd,* and show correct visibility.

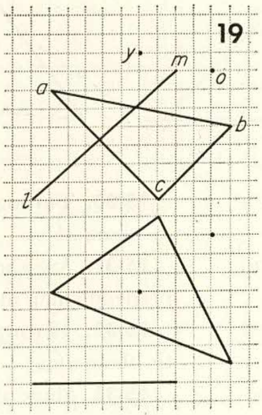
15-14. Line *rs* makes a true angle of 30° with the front plane. Show its position in the top view.

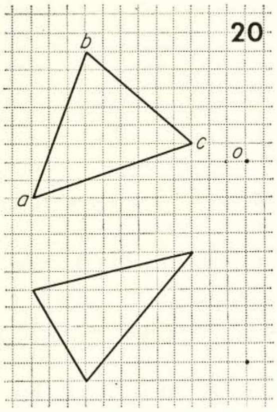
15-15. What is the distance between point *o* and the line *lm?*

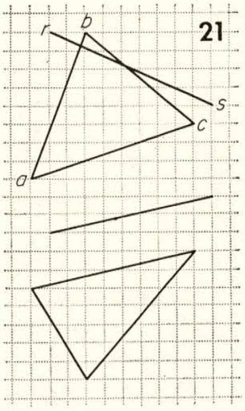
15-16. Show the distance from point *o* to the plane *abc.*

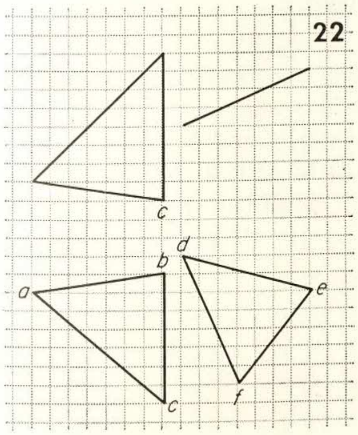
15-17. Is line *rs* parallel to plane *abc?* If so, what is the distance between them?

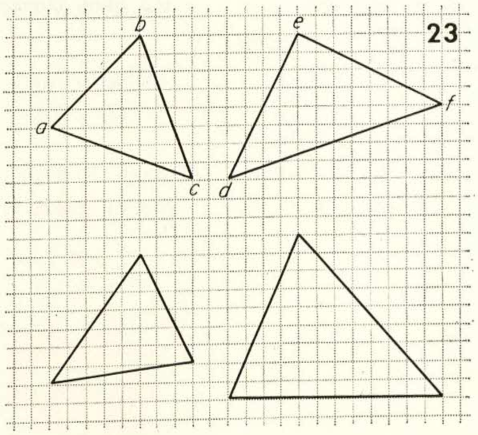


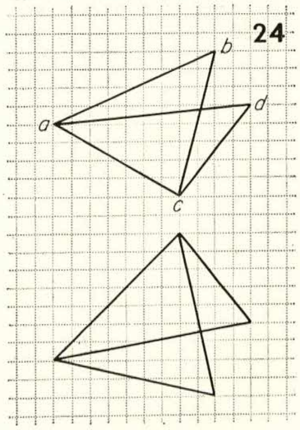












15-18. Is plane *abc* parallel to *def?* If so, what is the distance between them?

15-19. Is line *lm* parallel to plane *abc?* Through point *o,* draw a line parallel to the plane. How far is point *y* from the plane?

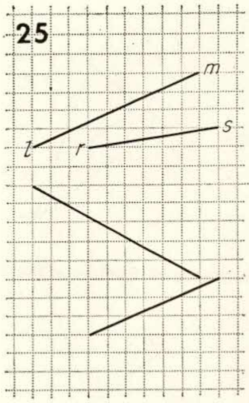
15-20. Through point *o,* draw a plane parallel to plane *abc.*

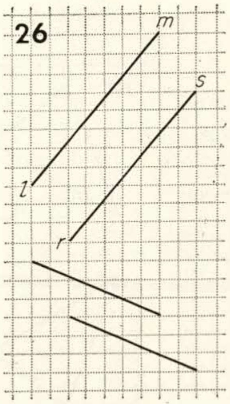
15-21. Show the angle between the line *rs* and the plane *abc.*

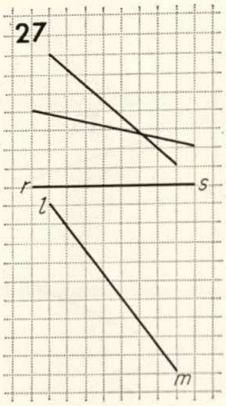
15-22. Show the line of intersection of planes *abc* and *def* in both given views.

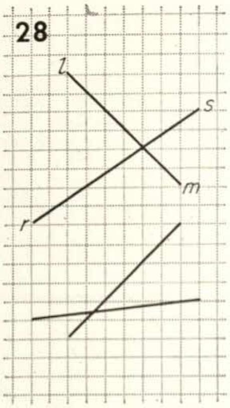
15-23. Show the line of intersection of planes *abc* and *def.* What is the angle between them?

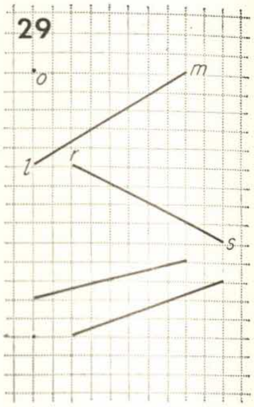
15-24. Show the angle between the given planes.

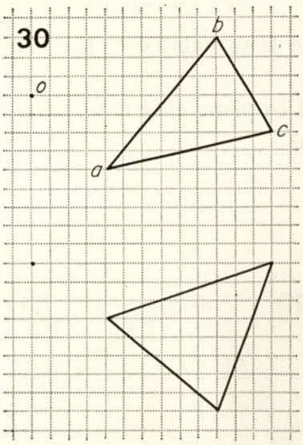


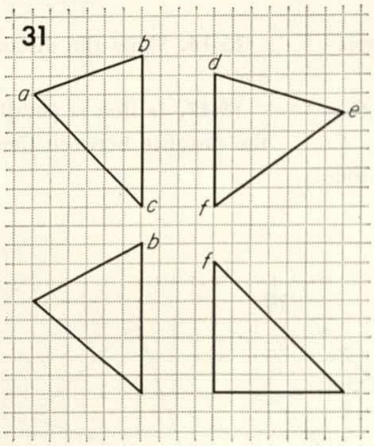


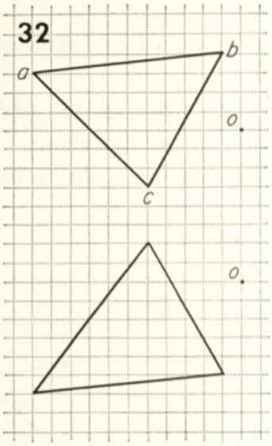


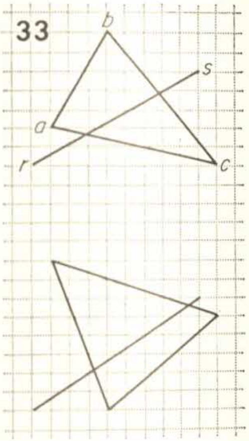












15-25. Show the angle between the given lines *lm* and *rs.*

15-26. What is the distance between the lines *lm* and *rs?* Show position in all views.

15-27. What is the distance from line *lm* to line *rs?* Show position in all views.

15-28. Show the shortest horizontal (level) line between lines *lm* and *rs.* Show position in all views.

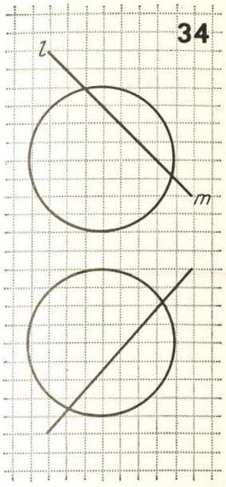
15-29. Through point *o,* draw a line intersecting lines *lm* and *rs.* Show this line in all views of projection.

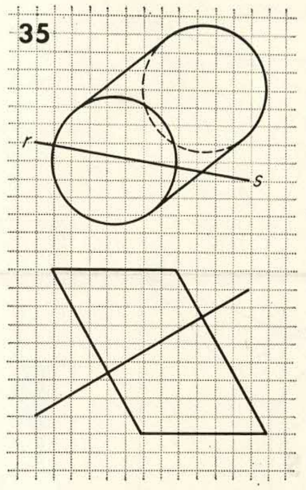
15-30. Through point *o,* draw a line perpendicular to plane *abc.*

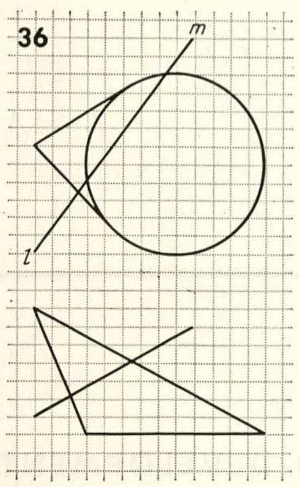
15-31. Are the planes *abc* and *def* parallel? Are they perpendicular to each other?

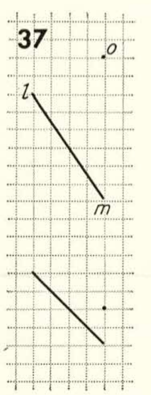
15-32. Through point *o,* draw a plane perpendicular to plane *abc.*

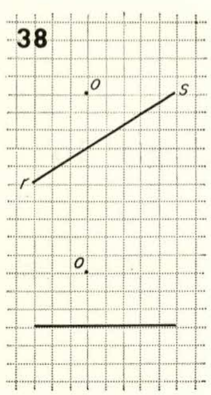
15-33. Show the piercing point of line *rs* with plane *abc.* Show correct visibility.

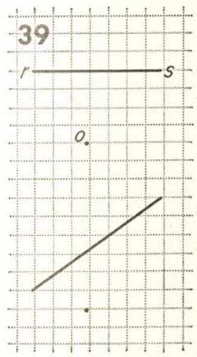


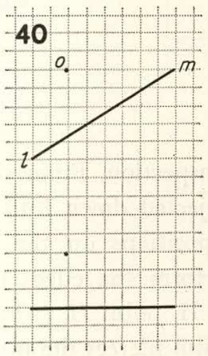


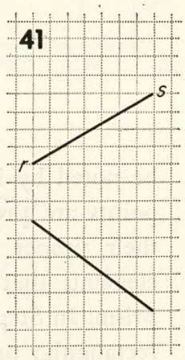


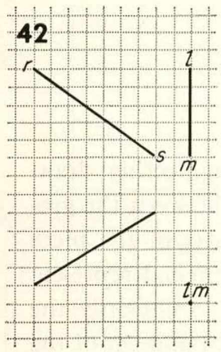


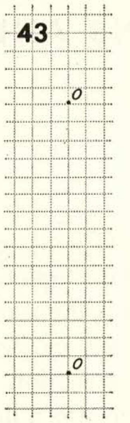


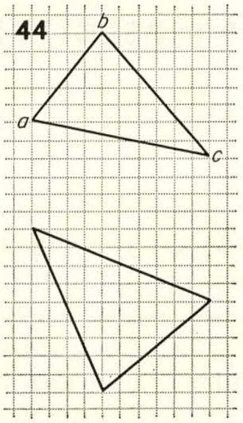












15-34. Does line *lm* pierce the sphere? If it does, show the piercing points with correct visibility.

15-35. If the line *rs* pierces the cylinder, show the piercing points and correct visibility.

15-36. If the line *lm* pierces the cone, show the piercing points and correct visibility.

15-37. Show the position of point *o* in the given views after it has been revolved 45° clockwise about line *lm*.

15-38. Show the position of point *o* revolved about line *rs* to its extreme right and extreme left position. (Show path of revolution in all views.)

15-39. Show the position of point *o* revolved about line *rs* to its nearest and farthest back position. (Show path of revolution in all views.)

15-40. Show the point *o* revolved about the line *lm* to its highest and lowest position. (Show path of revolution in all views.)

15-41. Find the true-length projection of line *rs* by revolution. Label the angle it makes with the front, top, and the side plane.

15-42. Show the position of the line *rs* after it has been revolved 45° counterclockwise about point *l* of line *lm*.

15-43. Draw a line through point *o* making an angle of 30° with the horizontal and 45° with the front plane. The line is 1½ in. long.

15-44. Find the true-shape projection of the plane *abc* by revolution.

Chapter 16

INTERSECTIONS AND DEVELOPMENTS

In the preparation of some engineering drawings, only the line of intersection between the geometric shapes that form the surfaces of the piece may be needed. However, in sheet-metal representations, the line of intersection is frequently the necessary first step in making a development of the surfaces. Finding the intersection between two geometric shapes, such as prisms, cylinders, cones, etc., is a somewhat complex procedure. However, the exact perimeter, or contour, of the intersection must be accurately determined before the part shown in a sheet-metal drawing can be fabricated. In sheet-metal work especially, it is important to represent such intersections accurately so that the shopworker can transfer the proper dimensions from the drawing to the material he is working on.

The complete line of intersection between two geometric shapes is formed by a series of points located at the intersection of lines lying on one surface with lines lying on the other. The lines are called *elements.* The selection, placement, and method of producing these elements are of prime importance in enabling the draftsman to represent complicated intersections quickly and easily.

16-1. Intersection of two prisms. Figure 16-1 shows two prisms that are to intersect in the general manner illustrated. It is necessary to find the exact line of intersection between them before their surfaces can be developed. In Step I, top view, the intersection points *A, C,* and *E* of the edges can be noted by inspection. From the top view, these points are projected down into the front view to their proper positions on the same straight-line elements that form the edges of the rectangular prism. In Step II, point *H* (where line *HG* of the rectangular prism pierces the upper base of the triangular prism) is found by first passing an imaginary cutting plane perpendicular to the top view, containing the line *HG,* and intersecting the triangular surface *JKL* in the line 1-2. The imaginary cutting plane is called a line-projecting plane because it is passed perpendicular to the plane of projection and projects (or appears) as a line or edge in that plane of projection. The line of intersection (line 1-2) between the line-projecting plane and the triangular plane *JKL* is projected into the front view. It will be noted that in the front view the line *GH* that lies in the line-projecting plane pierces *JKL* at the point *H* on the line of intersection 1-2 of the imaginary and given planes. The point *H* is now projected back to line 1-2 in the top view to establish the exact point of intersection of line *GH* in that view. This procedure is the proper method of establishing the location of the piercing point of any line representing an edge or element that intersects an inclined plane surface.

Step III illustrates the manner in which line *KL* of the triangular plane intersects plane *EFGH* of the rectangular prism. An imaginary line-project-

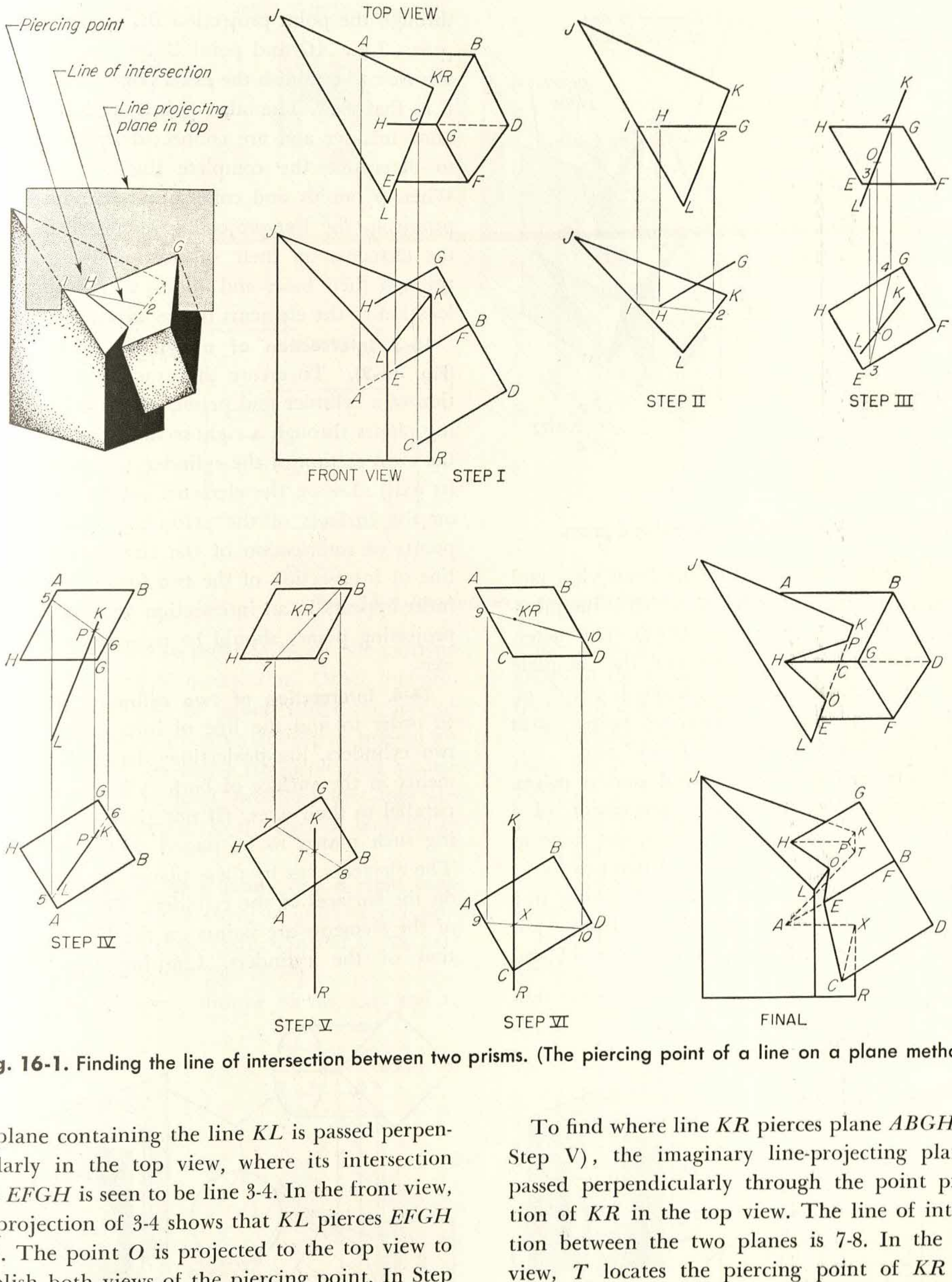


Fig. 16-1. Finding the line of intersection between two prisms. (The piercing point of a line on a plane method.)

ing plane containing the line *KL* is passed perpendicularly in the top view, where its intersection with *EFGH* is seen to be line 3-4. In the front view, the projection of 3-4 shows that *KL* pierces *EFGH* at *O*. The point *O* is projected to the top view to establish both views of the piercing point. In Step IV, the imaginary line-projecting plane containing *KL* is passed in the front view, where it intersects plane *ABGH* in line 5-6. The procedure outlined in the previous steps is followed to establish point *P* as the piercing point of *KL* on this plane.

To find where line *KR* pierces plane *ABGH* (see Step V), the imaginary line-projecting plane is passed perpendicularly through the point projection of *KR* in the top view. The line of intersection between the two planes is 7-8. In the front view, *T* locates the piercing point of *KR* with *ABGH*. The method of establishing the point at which *KR* pierces plane *ABCD* is shown in Step VI. The imaginary line-projecting plane is passed through the point projection of *KR* in the top view, where it intersects the given plane in line

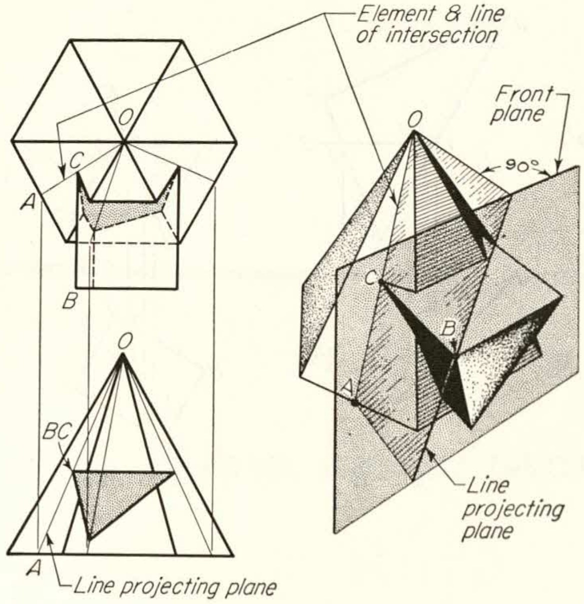


Fig. 16-2. Intersection of pyramid and prism.

9-10. Line 9-10 is projected to the front view and is intersected by *KR* at point *X*, which is the piercing point of *KR* in the plane *ABCD*. This determines the final piercing point, and the complete line of intersection of the two prisms is simply established by joining the piercing points with straight lines. See Secs. 15-27 and 15-37 also.

16-2. Intersection of a pyramid and a prism. The procedure for finding the intersection of a pyramid and a prism is, in general, the same as that used to find the intersection of two prisms. In Fig. 16-2, a line-projecting plane containing line *AO* is passed perpendicular to the front view through the base and apex of the pyramid and through the point projection *BC* of the triangular prism. Line *AO* and point *C* are projected to the top view to establish the exact point of intersection *C* in that view. The other points are located in the same manner and are connected by straight lines to determine the complete line of intersection. When pyramids and cones appear in intersection problems, the line-projecting planes that produce the elements on their surfaces should be passed through their bases and apexes to permit positive location of the elements in the adjacent view.

16-3. Intersection of a cylinder and a prism (Fig. 16-3). To secure the exact line of intersection of a cylinder and prism, pass the line-projecting planes through a right-section view that shows the cross section of the cylinder (perpendicular to its axis). Locate the elements cut by these planes on the surfaces of the prism and cylinder. The points of intersection of the elements lie on the line of intersection of the two forms. When a cylinder appears in an intersection problem, the line-projecting planes should be passed parallel to its axis.

16-4. Intersection of two cylinders (Fig. 16-4). In order to find the line of intersection between two cylinders, line-projecting planes that cut elements in the surface of both cylinders are passed parallel to their axes. (If not given, a view allowing such planes to be passed should be found.) The elements cut by these planes are then located on the surfaces of the cylinders. The intersections of the elements are points on the line of intersection of the cylinders. Limiting line-projecting

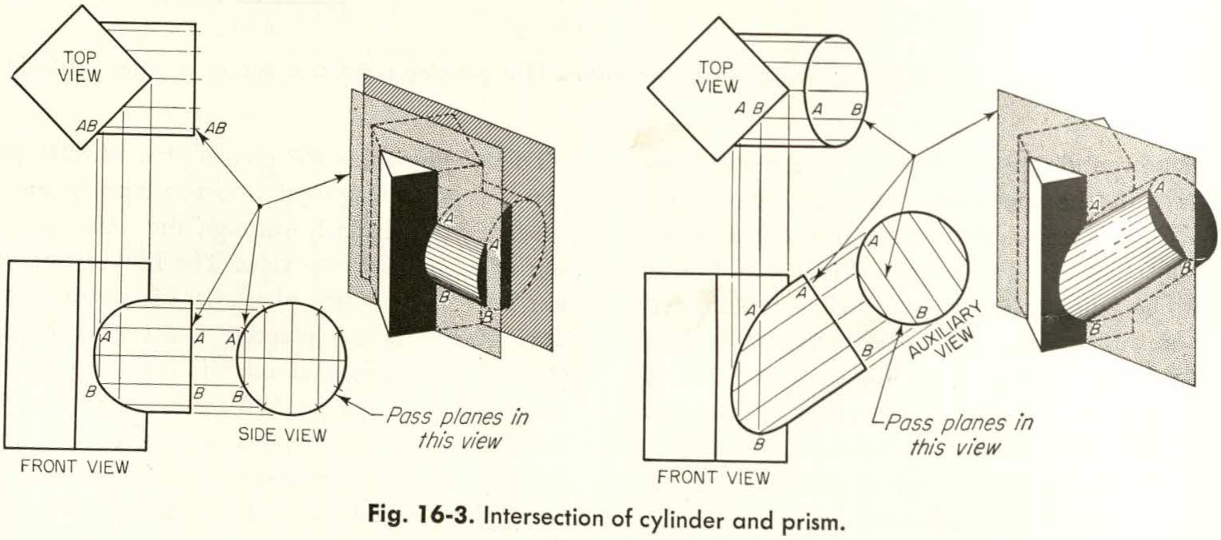


Fig. 16-3. Intersection of cylinder and prism.

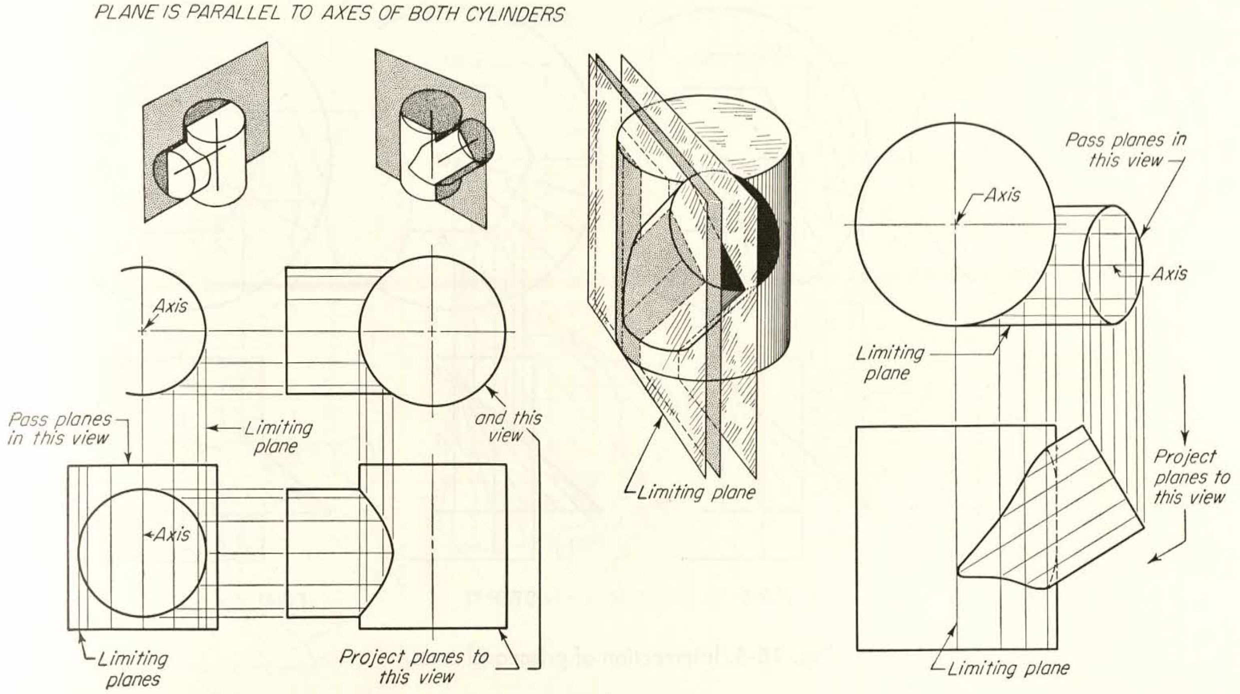


Fig. 16-4. Intersection of two cylinders.

planes are required in order to locate the extreme points on the line of intersection. Other line-projecting planes should be passed where the line of intersection appears to curve sharply or present an unusual contour. As many line-projecting planes as necessary may be used, provided that they are properly passed parallel to the axes of both cylinders.

16-5. Intersection of a plane and a right cone—conic sections. The curve of intersection produced by passing a plane perpendicular to the axis of a cone is a circle (see Fig. 16-5*a*).

If a plane is passed oblique to the axis and it makes a greater angle with the axis than the elements of the cone, the resulting curve of intersection is an ellipse (Fig. 16-5*b*).

If a plane is passed parallel to the elements of a cone, the curve of intersection is a parabola (Fig. 16-5*c*).

If a plane is passed parallel to the axis or makes a smaller angle with the axis than the elements make, the curve of intersection is a hyperbola (Fig. 16-5*d*).

16-6. Intersection of a prism and a cone (Fig. 16-6). The line of intersection between the prism and the cone shown in Fig. 16-6 is made up of a

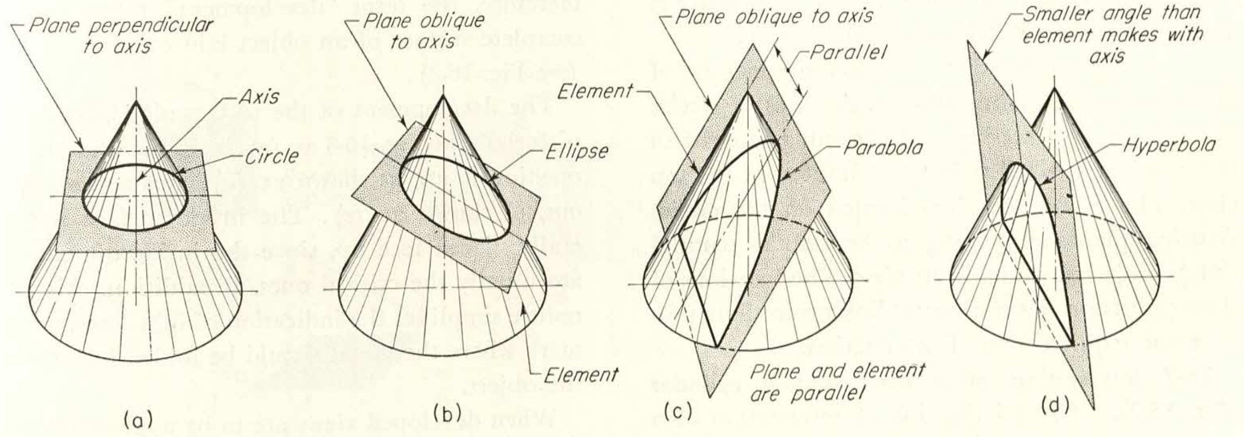


Fig. 16-5. Conic sections.

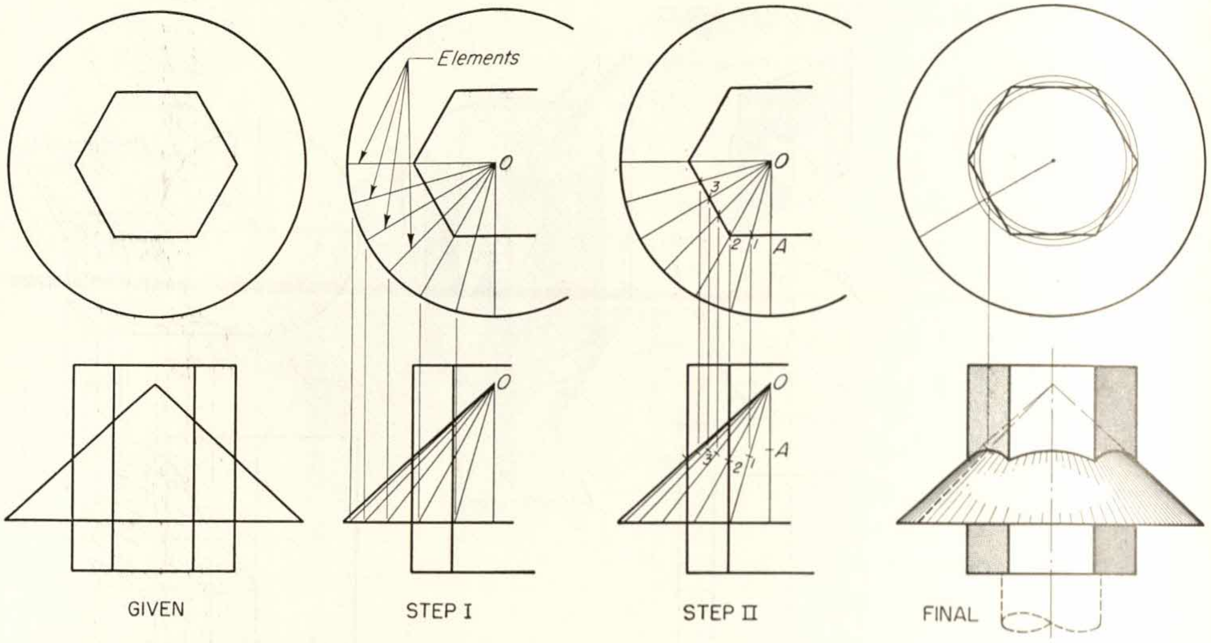


Fig. 16-6. Intersection of prism and cone.

series of hyperbolas, since the lateral surfaces of the prism are parallel to the axis of the cone. In the figure, the prism and cone are to intersect as shown. In Step I, pass the line-projecting planes through the apex and base of the cone in the top view, and locate them in the front view. In Step II, by inspecting the top view, we note the piercing points of the elements with the sides of the prism along its perimeter. These points are projected to their proper position on the elements in the front view, where they locate the line of intersection of the cone and the prism. Points *A* and 3 are at the same height in the front view. The front view in the final step shows the true hyperbolic curves of the chamfered head of a bolt (which in practice is always shown by a series of circular arcs).

The final step also shows an alternate method of finding the line of intersection. A series of circles of the cone, intersecting and becoming tangent to the prism at selected points, are located in the top view. The points are then located on the circles (cutting planes appearing as horizontal parallel lines) projected to the front view. The locations of these points on the horizontal-line projections produce the required line of intersection.

16-7. Intersection of a cone and a cylinder (Fig. 16-7). To find the line of intersection of a cone and a cylinder, the imaginary cutting planes should be passed through the vertex and base of the cone and parallel to the axis of the cylinder so as to cut the elements in the surfaces of both forms. A view allowing such planes to be passed should be found if not given. A plane creating extreme elements is necessary to locate the boundary point *A* on the line of intersection.

16-8. Developments. Cylinders, ducts, containers, and other similar forms are usually cut from flat metal sheets and then rolled or folded into the required shape. For this reason, the draftsman must represent on the drawing sheet the shape and dimensions of sheet-metal parts, not only in their final form but also in their "developed," or "rolled-out," form. As applied to engineering drawing, therefore, the term "development" refers to the complete surface of an object laid out on a plane (see Fig. 16-8).

The development of the rectangular box shown pictorially in Fig. 16-8 at (*a*) is simply a matter of opening it up, as shown at (*b*), and spreading it out, as shown at (*c*). The inside surface is generally placed face up, since the inside dimensions are usually the critical ones. In addition, this procedure simplifies the indication of fold lines, which mark where the metal should be folded in forming the object.

When developed views are to be used as patterns or templates, they must be drawn with strict accuracy. The side of the surface shown should be

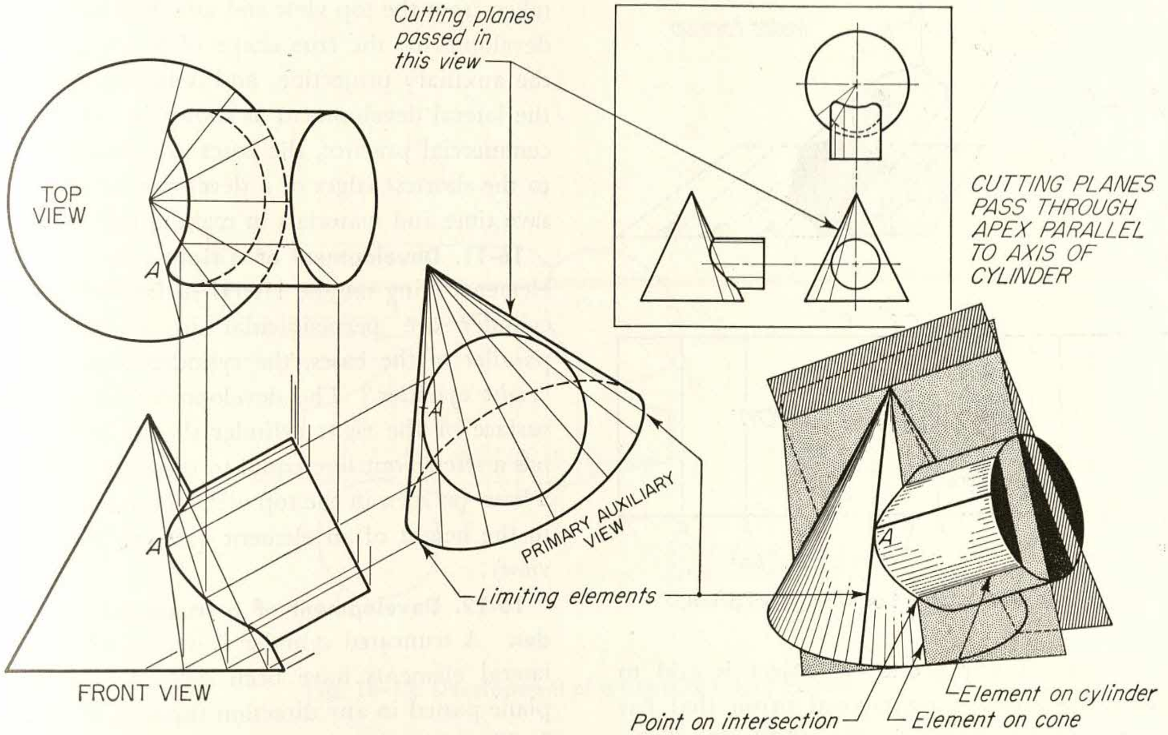


Fig. 16-7. Intersection of cone and cylinder.

clearly indicated by a note. Information for the angle of bend and the manner of bending, up or down from the flat, is specified along the bend line on the surface to which it applies. All seams are clearly shown drawn in with thin lines. The development is plainly marked "Pattern for . . . ," "Template for . . . ," or "Development of. . . ." The complete development, as it appears on the sheet with its proper notes, is shown in Fig. 16-8*d*. Each surface is in its true size, shape, and position. Each is joined to its neighbor by a common edge, a thinly drawn fold or mold line.

16-9. Development of a hexagonal prism. In the development of the hexagonal prism shown in Fig. 16-9, each side is placed beside its neighbor in its true shape and size and is spread out, inside face up, along a stretch-out line, which is equivalent to the perimeter of the base of the prism. Note that dimension *A* of each side is taken from the front view and *B* from the top. (Elements are always shown on all developments drawn in with thin lines.)

16-10. Development of a truncated pentagonal prism. A plane that cuts all elements of the lat-

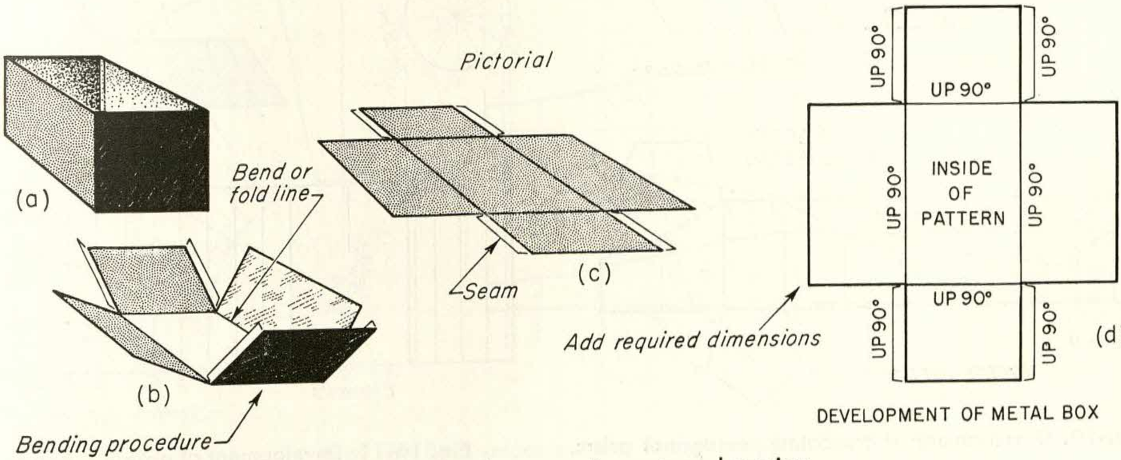


Fig. 16-8. Development of a rectangular prism.

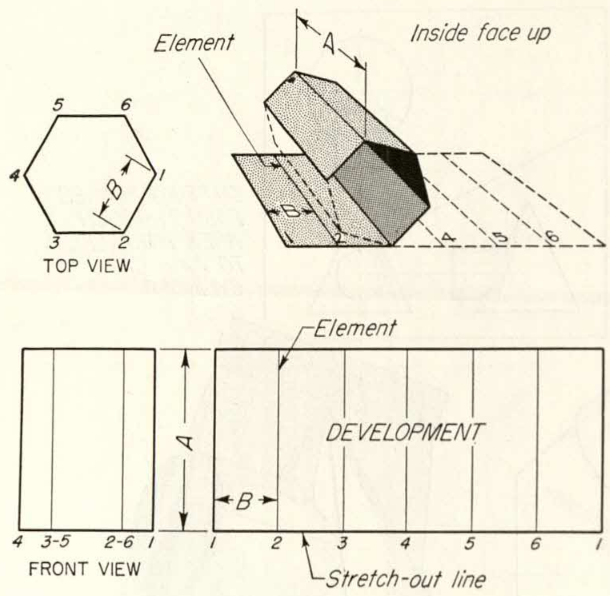


Fig. 16-9. Development of hexagonal prism.

eral surfaces of any geometric object is said to *truncate* the form. A pentagonal prism that has been truncated is shown in Fig. 16-10. The front and top views and a true-shape auxiliary projection of the top base are given, and it is desired to make a development of the form. On the stretch-out line, which is equal to the perimeter of the base, mark off the distances 1-2, 2-3, etc., shown in the top view. The true lengths of the edges of the sides are seen in the front view and may be either marked off on perpendiculars erected at points 1 to 5 or projected directly from the front view to the development. The true shape of the lower base is taken from the top view and attached to the lateral development; the true shape of the upper base is the auxiliary projection, and it is also attached to the lateral development as shown in the figure. In commercial practice, the bases are always attached to the shortest edges of a development in order to save time and materials in making the seams.

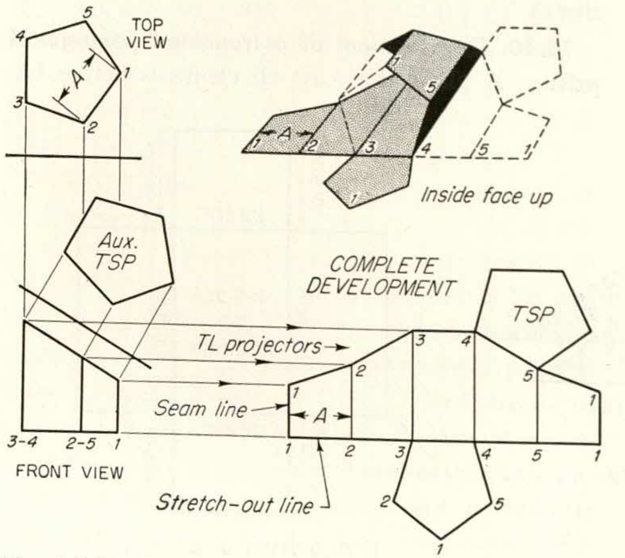


Fig. 16-10. Development of truncated pentagonal prism.

16-11. Development of a right cylinder. If the elements lying on the lateral surface of a circular cylinder are perpendicular to a right section parallel to the bases, the cylinder is said to be a "right cylinder." The development of the lateral surface of the right cylinder shown in Fig. 16-11 has a stretch-out line equal to the circumference of a base (as seen in the top view) and a width equal to the height of an element (as seen in the front view).

16-12. Development of a truncated right cylinder. A truncated cylinder is one in which all the lateral elements have been severed by a cutting plane passed in any direction through the cylinder. In Fig. 16-12, the top view of the cylinder is divided into 12 (or 16 or 24) parts, and the points are projected as elements on the lateral surface seen in the front view. The stretch-out line is taken along the intersection of a plane passed perpendicular to the axis and is equal in length to the circumference of the cylinder. The lengths of the lateral elements are measured or projected from the front view. They are cut off at their true lengths as they extend above and below the stretch-out line. A french curve is used to join the points to complete the

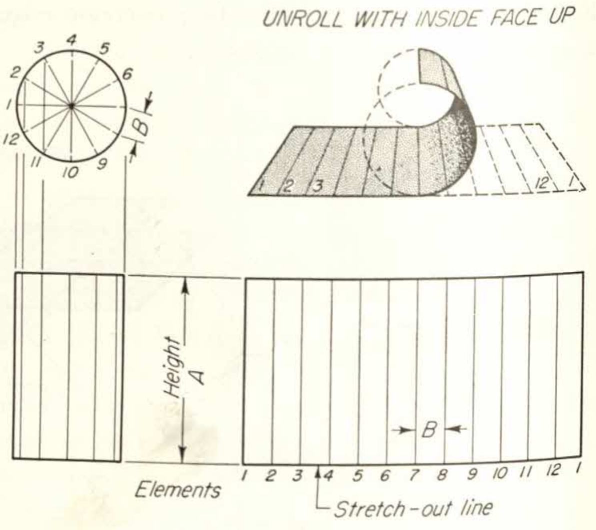


Fig. 16-11. Development of a right cylinder.

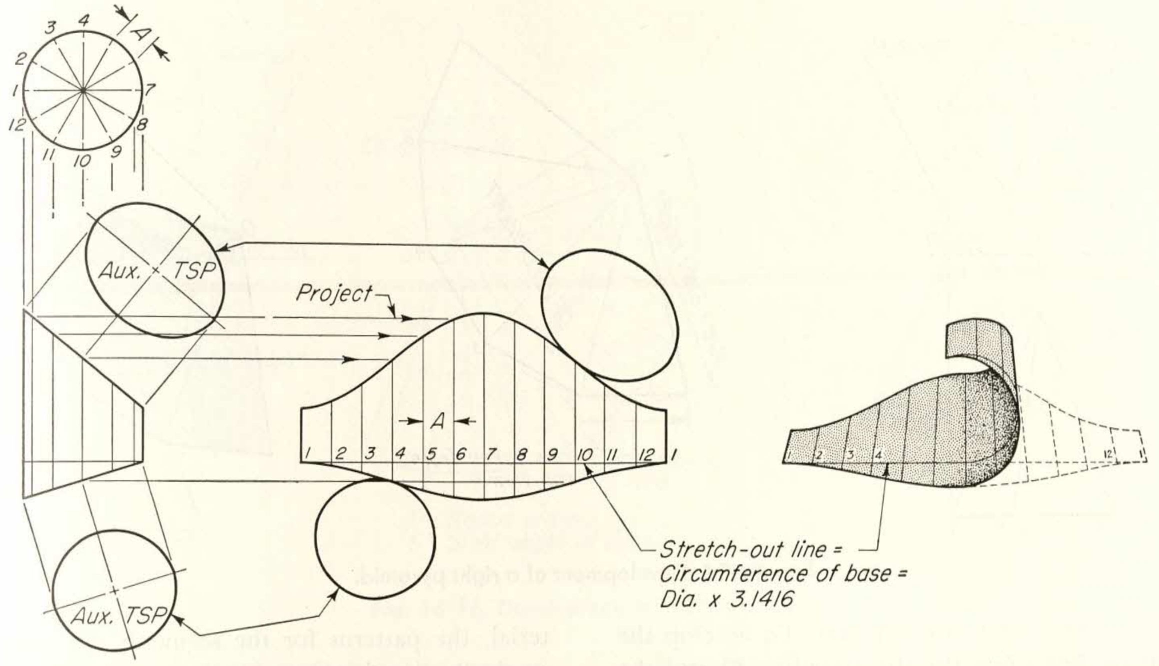


Fig. 16-12. Development of a truncated right cylinder.

lateral development. The auxiliary true-shape projections of the upper and lower bases may be attached to the development of the lateral surface as shown.

A practical application of the principles involved in the development of a truncated right cylinder is seen in the development of the five-piece elbow shown in Fig. 16-13. In order to produce the elbow from sheet metal, the surfaces must be developable; that is, they must lie flat on a plane surface. Since it is obviously impossible to make a single development for the entire surface of the elbow, the material is divided into a convenient number of smaller, developable segments which can be joined together in the shop to make the desired piece. In this case, the five segments that make up the elbow are all truncated right cylinders. It will also be noted that the two pieces at the extremities are identical, as

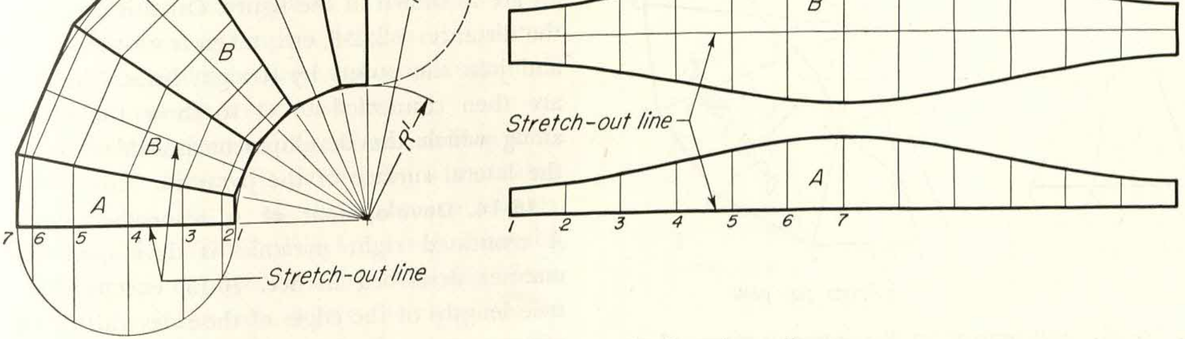


Fig. 16-13. Development of a five-piece elbow.

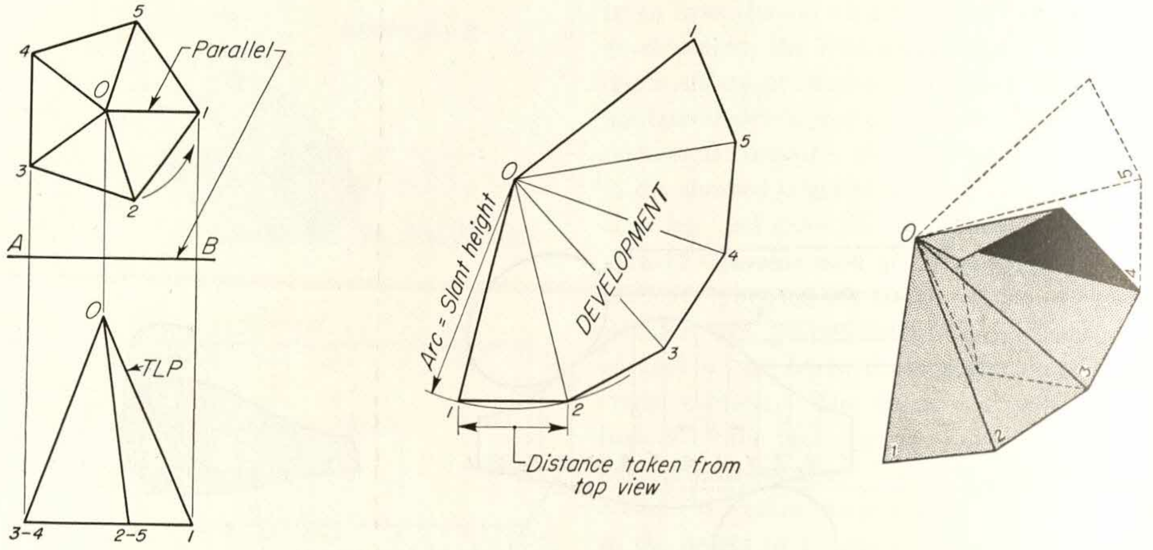


Fig. 16-14. Development of a right pyramid.

are the three intermediate pieces. To develop the segments, first draw the throat radius R^1 and the heel radius R^2. Divide the base into 12, 16, or 24 parts. In this case, the base is divided into 12 parts, 6 of which are visible. Project the points of division as elements on the lateral surface of the five radially proportioned pieces of the elbow. Then draw the stretch-out lines as shown in the figure, and at points 1, 2, 3, etc., measure off or project the lengths of the lateral elements. To conserve material, the patterns for the segments are laid out on the flat metal as shown at the upper right corner of the illustration. The shape of the developed segments remains the same, but the seams are placed alternately along the long and short elements of the pieces.

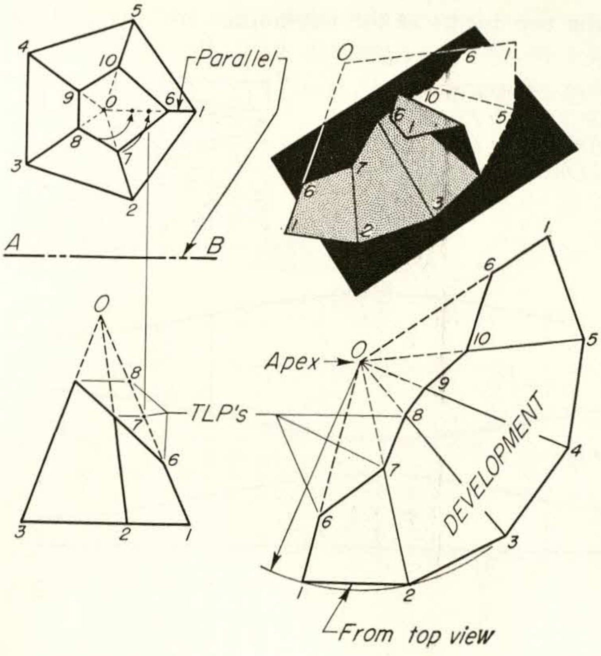


Fig. 16-15. Development of the lateral surface of a truncated pyramid.

16-13. Development of a right pyramid. A right pyramid is one in which the altitude (a perpendicular from the apex to the base) coincides with the axis (a straight line connecting the apex with the midpoint of the base). The development of a right pyramid consists in drawing the true surfaces of the sides and attaching them together at their edges, which intersect at the apex. In Fig. 16-14, the top view shows the true lengths of the edges of the base (distances 1-2, 2-3, etc.). The front view shows the true length of the edge along the sides (distance *O*-1). From point *O* (corresponding to the apex), and with a radius equal to the true length of the edge of a side (*O*-1), strike an arc as shown in the figure. On this arc, step off the distances 1-2, 2-3, etc., taken from the top view, and join the points by straight lines. The points are then connected to *O* to show the elements along which the development is folded to shape the lateral surface of the pyramid.

16-14. Development of a truncated pyramid. A truncated right pyramid is developed in the manner described in Sec. 16-13, except that the true lengths of the edges of the sides (all of which are not evident by inspecting the given views) are found by revolving them parallel to the reference

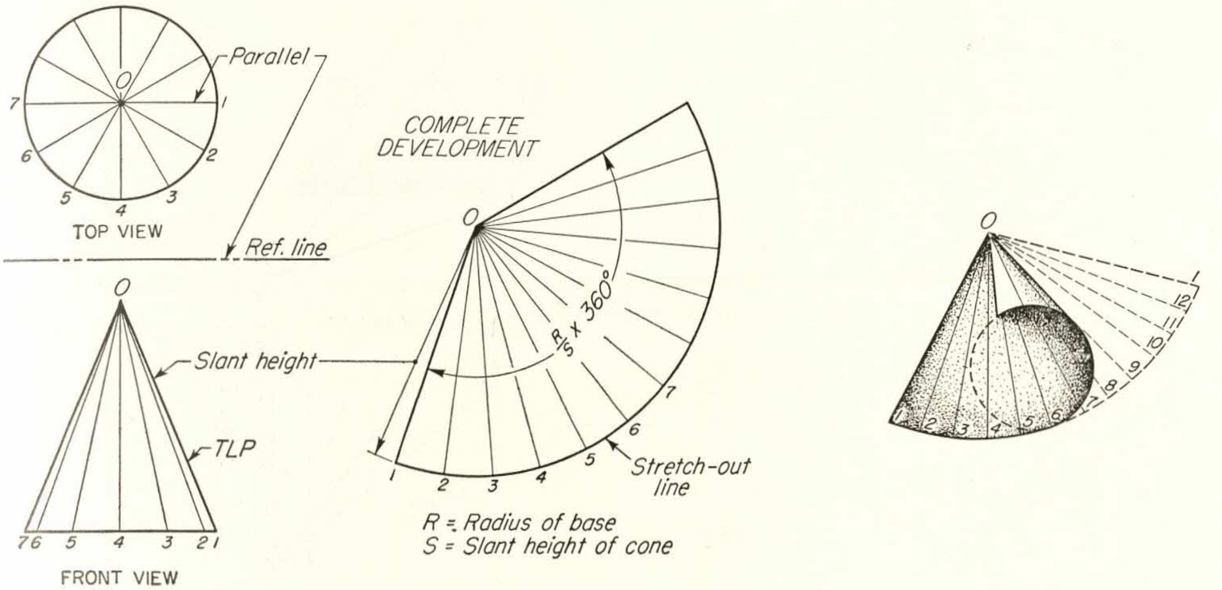


Fig. 16-16. Development of a right cone.

line in the top view and projecting the revolved positions to the front view. In the front view of Fig. 16-15, the edge *O*-1 is parallel to the projection or picture plane and therefore shows in its true length. With this distance as a radius, strike an arc from point *O* in the development to form the stretch-out line. On this line, mark off the chords 1-2, 2-3, etc., which are the true lengths along the base taken from the top view. Now draw the elements intersecting at the apex *O*. Along these elements, step off the true lengths of the sides 1-6, 2-7, 3-8, etc., as found by revolving the lines in the top view and projecting to the front view. Join points 6, 7, 8, etc., with straight lines to complete.

16-15. Development of a right cone. In the development of the right cone shown in Fig. 16-16, the slant height of the cone *O*-1 is used as a radius to strike an arc from the apex *O*. The exact extent of the stretch-out line may be computed from the formula given, or the perimeter of the base may be first divided into a convenient number of segments in the top view and then these distances stepped off with dividers on the stretch-out line.

16-16. Development of the lateral surface of a truncated right cone. In developing a truncated right cone (Fig. 16-17), the first steps are exactly the same as those described in Sec. 16-15. Find the true lengths of the elements by revolving them parallel to the front view, where their projections will show as true lengths along the extreme element *O*-1. Then mark off the true-length elements on lines *O*-1, *O*-2, etc., in the development. An irregular curve is used to draw the curve through the points *A*, *B*, *C*, *D*, etc., of the development.

16-17. True-length diagram. For the more complicated developments, it is helpful to prepare a separate true-length diagram from which the true lengths of elements can be measured with a pair of dividers and transferred to the progressing develop-

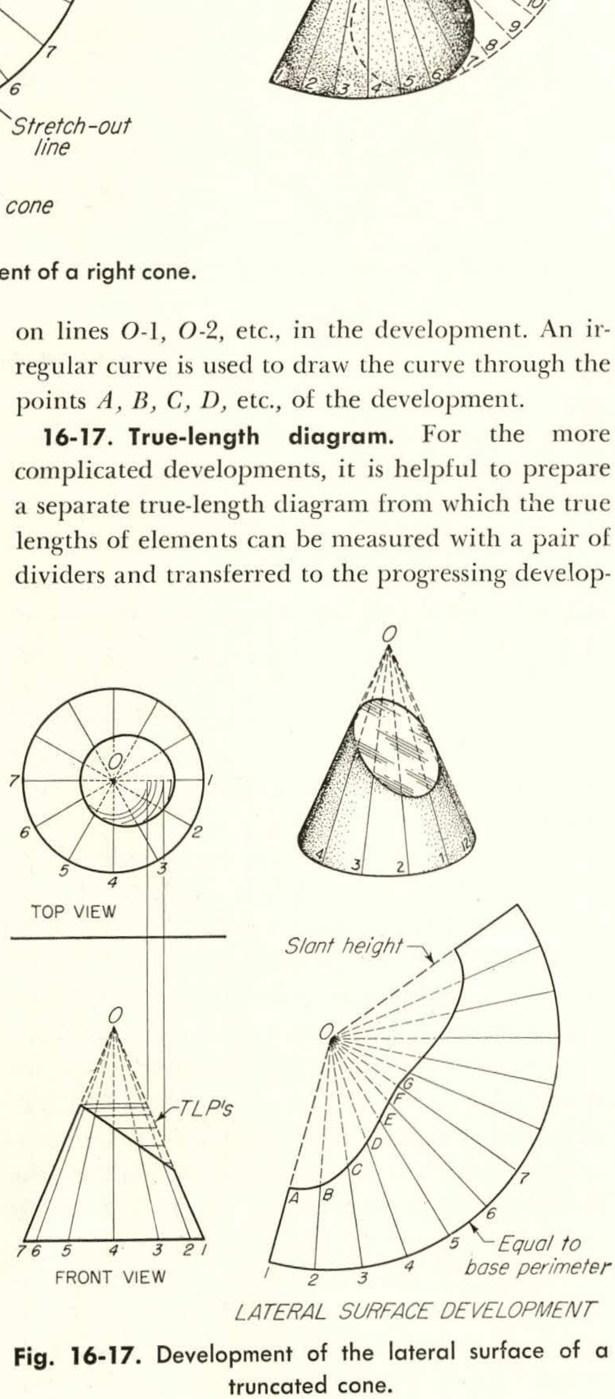
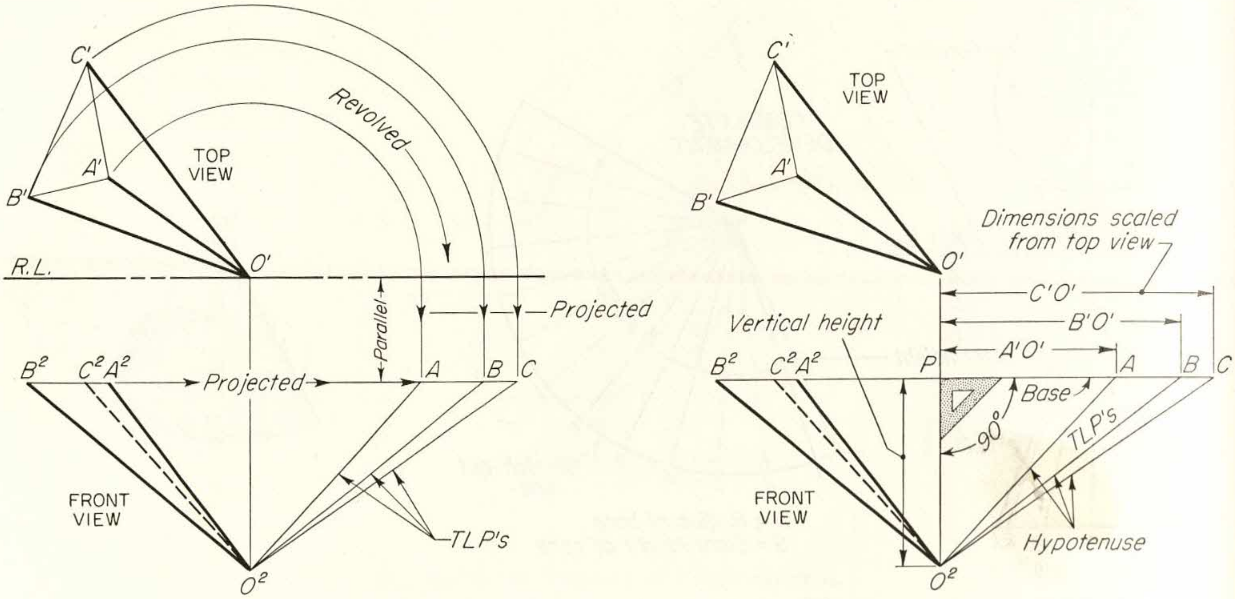


Fig. 16-17. Development of the lateral surface of a truncated cone.



TLP DIAGRAM by REVOLUTION

(a)

TLP DIAGRAM - HYPOTENUSE METHOD

(b)

Fig. 16-18. True-length diagrams.

ment. Figure 16-18 illustrates two ways in which independent true-length projection diagrams may be drawn. The triangular solid with its vertex at *O* is given in the top and front views. By inspection, it can be seen that the lengths of the edges *AB, BC,* and *CA* of the triangular base show in their true lengths in the top view, and so no diagram is needed for them. *OA, OB,* and *OC,* however, are not seen in their true lengths in either of the given views. Therefore, a separate diagram is constructed to show these lines in their true lengths.

One method of finding the true lengths of the lines is based on the principle of *revolution.* In Fig. 16-18*a,* with O^1 as a center, revolve the lines O^1A^1, O^1B^1, and O^1C^1 until they lie parallel to a frontal reference line drawn through O^1, as shown in the top view. Then project the points vertically down to intersect with lines projected from the front view (points A^2, B^2, and C^2) toward the right parallel to the reference line. The intersections determine the location of the points *A, B,* and *C* on the true-length projections drawn from these points through the vertex O^2 in the front view.

If insufficient space is available to allow the revolution procedure just described, it may be necessary to set up a different type of true-length diagram known as the *hypotenuse diagram.* The procedure for developing this type of diagram is illustrated in Fig. 16-18*b* and is based on the fact that the true length of each line is the hypotenuse of a triangle in which the altitude is the height of the line in the front view and the base is the length of the projection of the line in the top view. For instance, in triangle A^2O^2P, O^2P is the vertical height of A^2O^2 seen in the front view, the base *PA* is measured from the top-view projection of the line O^1A^1, and the hypotenuse O^2A of the right triangle AO^2P seen in the projection is the true-length projection of the line *OA.*

16-18. Development by triangulation. The lateral surfaces of the form shown in Fig. 16-19 can be developed by arranging suitable triangles on the surface and laying them out side by side to form the development. Such a procedure is called *triangulation.* The true length of each element is determined by the hypotenuse principle discussed in Sec. 16-17, in which it was shown that the true-length projection of an element is the hypotenuse of a right triangle in which one leg is equal to the length of the projection of the line as seen in the top view and the other leg is the altitude of the line as seen in the front view.

In the illustration, the oblique surfaces 1-2-3-4 and 3-4-5-6 are divided into separate, easily developable triangles by the lines 1-3 and 3-5. The true lengths of the lines are determined by the hypotenuse method, as shown, and the required

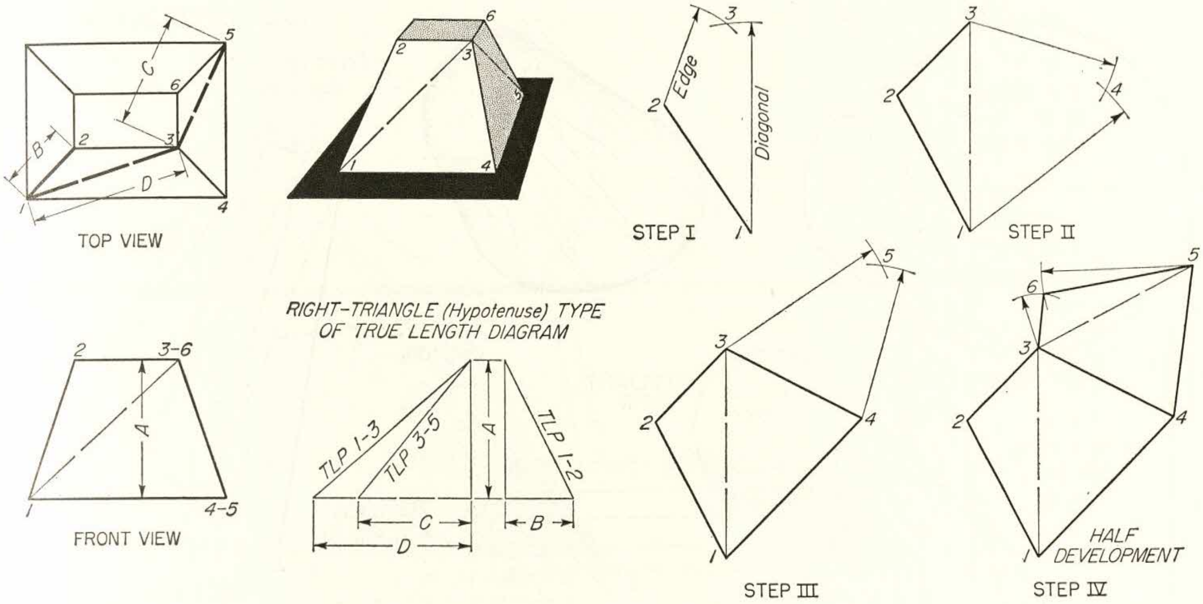


Fig. 16-19. Triangulation of surfaces.

half development is laid out as follows: In Step I, start by laying out edge 1-2 equal to its length taken from the true-length diagram. Then, with a radius equal to the true length of the diagonal 1-3 and with point 1 as a center, strike an arc. Strike another arc intersecting the first by taking the true distance of 2-3 from the top view and using 2 as the center. The intersection of the arcs determines the location of point 3. In Step II, the procedure is similar, and the two triangles with the diagonal 1-3 as a common side outline the true shape of the lateral side 1-2-3-4 of the pyramid. Steps III and IV continue this process to establish the complete half development.

16-19. Development of an oblique cone. The triangulation method is generally used for the development of an oblique cone. In Fig. 16-20, the front and top views of the cone are shown. The true-shape projection of the base in the top view is divided into a convenient number of parts, and the elements *O*-1, *O*-2, etc., are drawn in the top view and projected to the front view. The true-length projections of the elements are then found by revolution. The triangles formed by the ele-

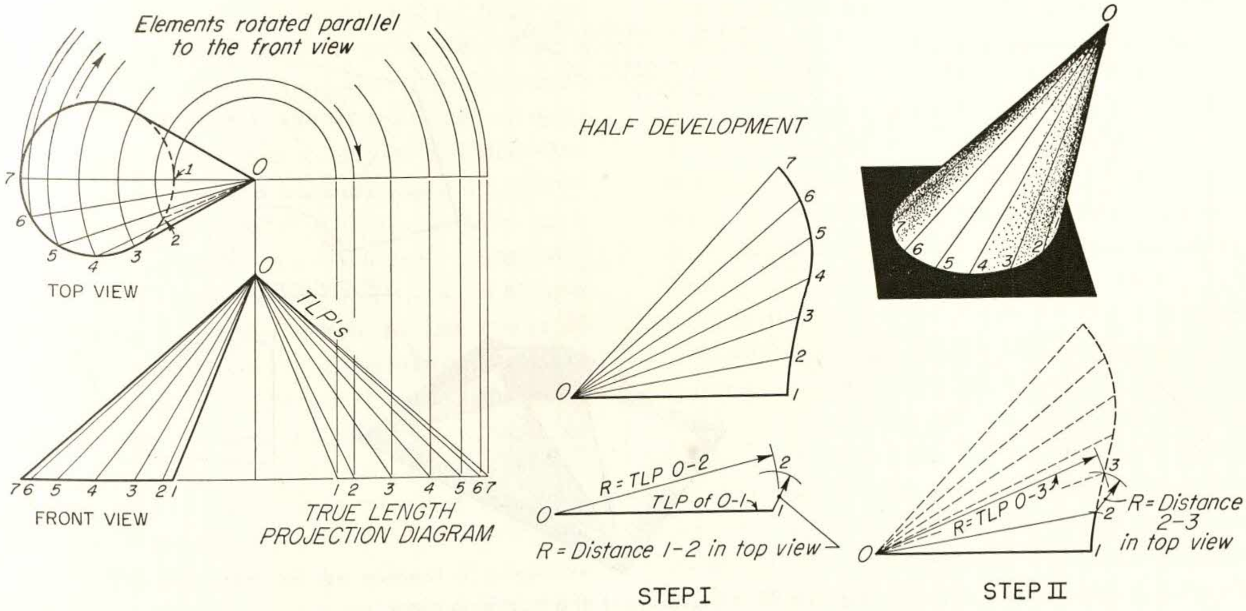

Elements rotated parallel to the front view
O
1
2
3
4
5
6
7
TOP VIEW
O
TLP's
7 6 5 4 3 2 1
FRONT VIEW
1 2 3 4 5 6 7
TRUE LENGTH PROJECTION DIAGRAM
HALF DEVELOPMENT
O
1
2
3
4
5
6
7
R = TLP O-2
TLP of O-1
R = Distance 1-2 in top view
STEP I
R = TLP O-3
R = Distance 2-3 in top view
STEP II

Fig. 16-20. Development of an oblique cone.

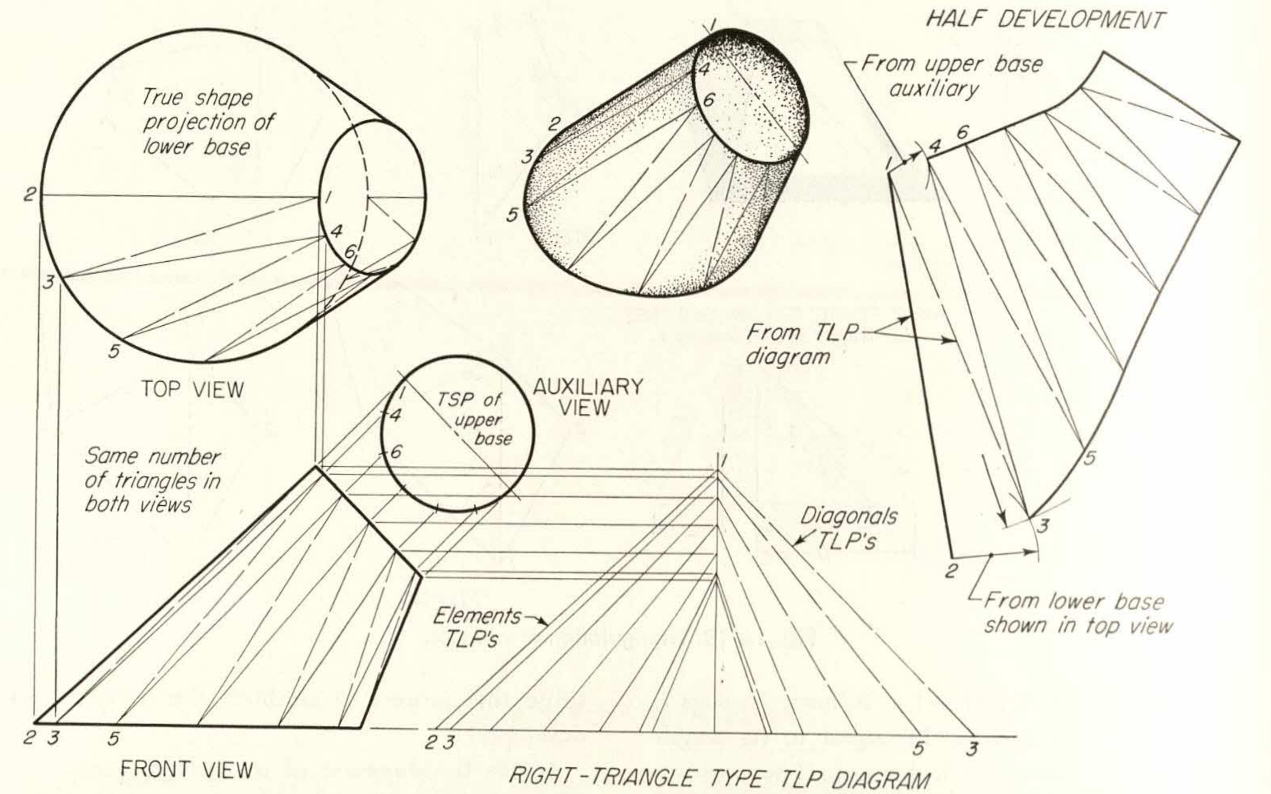

HALF DEVELOPMENT
True shape projection of lower base
From upper base auxiliary
1
2
3
4
5
6
TOP VIEW
TSP of upper base
AUXILIARY VIEW
From TLP diagram
Same number of triangles in both views
Diagonals TLP's
Elements TLP's
From lower base shown in top view
2 3 5
FRONT VIEW
2 3
5 3
RIGHT-TRIANGLE TYPE TLP DIAGRAM

Fig. 16-21. Development of a transition piece.

ments are laid out consecutively in their true shapes, being joined at the elements that form common edges. Although the final development is only a close approximation of the surface of the cone, it satisfies commercial requirements.

16-20. Development of transition pieces. A transition piece is a form that connects openings of different shapes or different sizes. The transition piece shown in Fig. 16-21 connects two circular pipes of different diameters whose axes intersect. Although this piece is not the frustum of an oblique cone, its development may still be most practically accomplished by triangulation. In triangulating the surfaces, the same number of tri-

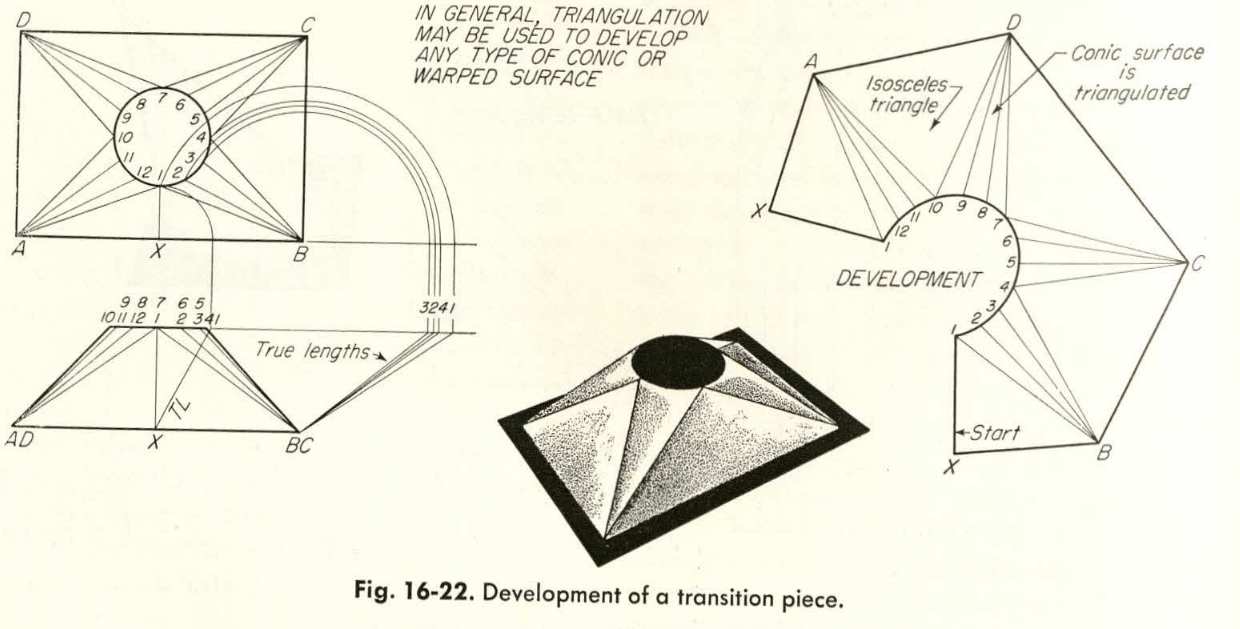


Fig. 16-22. Development of a transition piece.

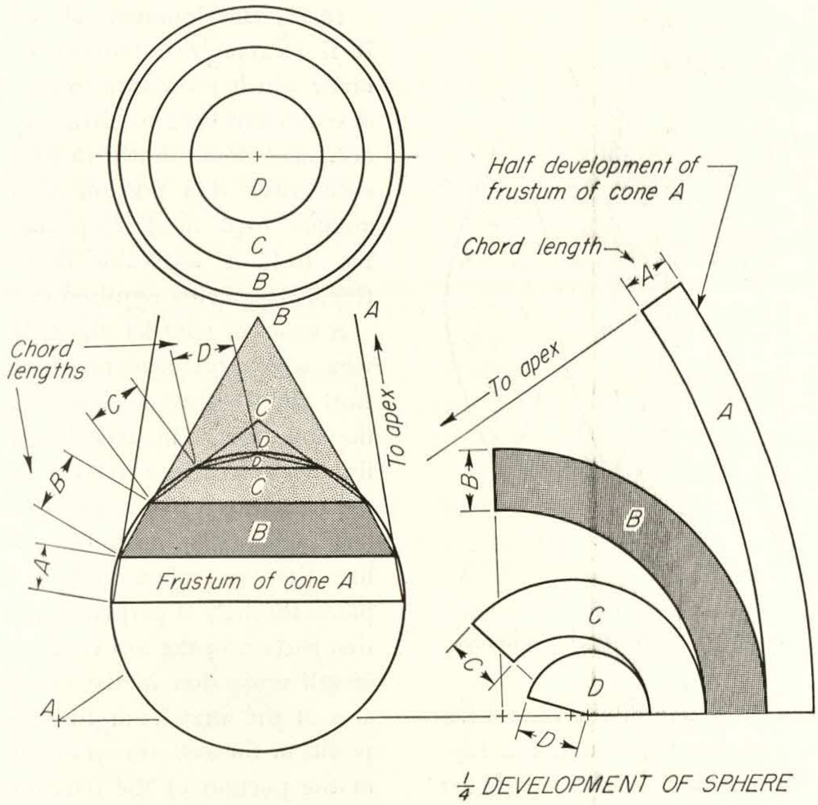


Fig. 16-23. Development of the surface of a sphere.

angles (in proper projection from one view to the other) are laid out in both the top and front views. It should also be noted that, since the upper base is not parallel to the plane of projection for the top or front views, the true distances 1-4, 4-6, etc., are taken from the true-shape auxiliary view.

The transition piece shown in Fig. 16-22 connects a circular pipe with a rectangular duct. A study of the pictorial indicates that the surface may be broken down into four isosceles triangles whose bases connect with the rectangular duct and four conic surfaces whose upper edges form the circle of connection with the circular pipe. The isosceles triangles are developed by using their outlining edges, and the conic surfaces are triangulated. The length *BX* (one-half the base line of the isosceles triangle) is taken directly from the top or front views, and a true-length diagram is produced to show the other required true lengths. Start the development with line 1-*X*, and attach the triangulated portions along their common numbered elements in the regular order.

16-21. Development of the surface of a sphere. The surface of a sphere is a double-curved surface; that is, it is generated by a curved line and contains no straight-line elements. Such surfaces are not, strictly speaking, developable; however, their developments may be approximated by dividing the surfaces into smaller segments that are developable. Accordingly, two different ways in which a sphere may be approximately developed are given here.

In Fig. 16-23, the surface of the sphere has been cut by a series of parallel planes. Each section is considered to be part of the surface of an imaginary cone whose apex may be found by extending the sides (chords). The development pictured is one-quarter of the surface of the sphere (or a half development of the frustums of the cones).

In Fig. 16-24, a series of vertical planes is passed through the axis in the top view cutting meridian lines on the surface. Parallel planes are passed perpendicular to the axis in the front view and are projected to, and shown as circles in, the top view. The development shows the true shapes of each of the small divisions obtained by rectifying the arcs on the circumference of the meridians (from front view) and of the arcs of the circles (from top

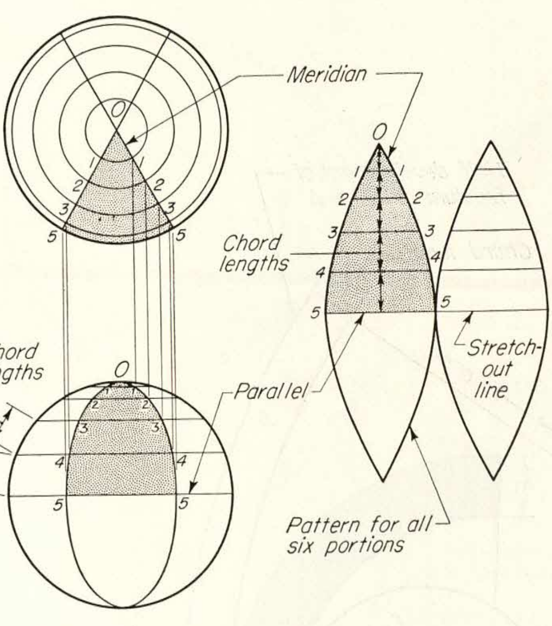


Fig. 16-24. Development of the surface of a sphere.

view). After the pattern of one of the large divisions has been developed, it may be used as a replica for the remaining divisions, which should be placed on a stretch-out line equal to the circumference of the sphere.

16-22. Development of an octagonal dome. It is extremely important for the draftsman to know which procedure to apply in laying out the development for a particular type of surface. In the octagonal dome shown in Fig. 16-25, for example, each piece is a portion of a cylinder, and the method used to develop the cylinder shown in Fig. 16-12 is applicable here (with several additional steps being required in this case).

A series of parallel planes is passed in the front view which cut elements in the surface. These in turn are projected to show in their true lengths in the top view. The true length of the stretch-out line *OC* for surface *AOG* is seen in the side view; the true length of the stretch-out line *OD* for surface *EOF* is seen in the front view. The stretch-out line *KO* for surface *EOG* is found by passing a plane through *O* perpendicular to the elements of that surface in the top view and obtaining its true-length projection in the auxiliary. Rectifying the arcs of the stretch-out lines and stepping off the points of the surfaces on either side of them result in the portion of the development shown at the left in the illustration. These may be used as patterns for the remaining similar surfaces.

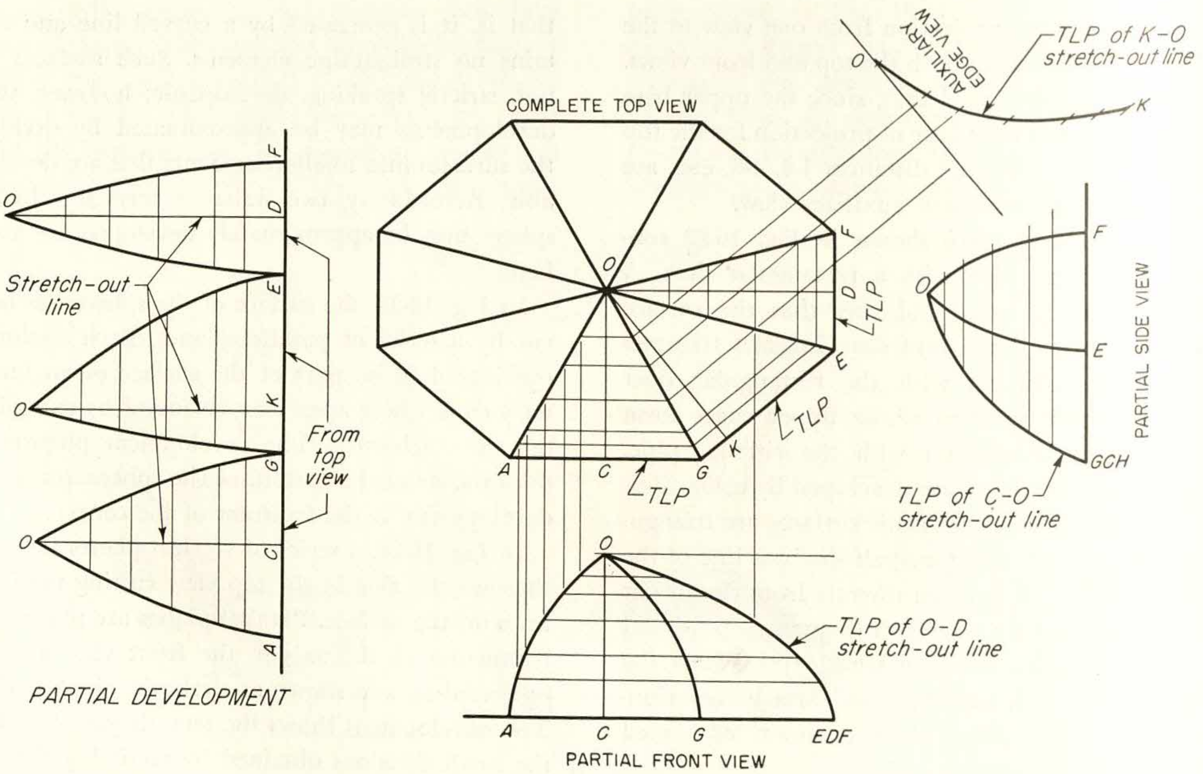


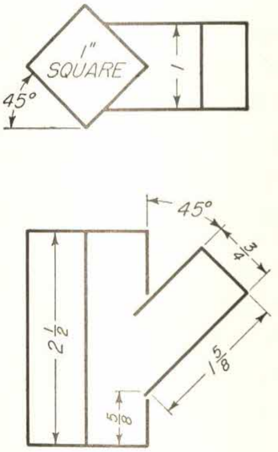
Fig. 16-25. Development of an octagonal dome.

PROBLEMS

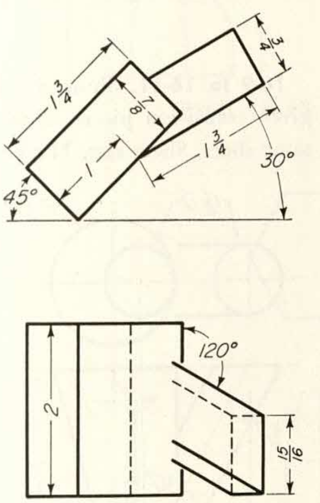
The problems that follow have been especially selected to afford practice in the application of the principles of intersections and developments. It is suggested that a few of the more complicated objects be drawn and their patterns cut out as a check against the accuracy of the students' work. All the objects may be assumed to be hollow and constructed of thin metal. The drawings may be made on 8½- by 11-in. or 11- by 17-in. sheets, depending on the scale selected. The placing and numbering of points on the objects will simplify the drafting procedure.

16-1 and 16-2. Find the line of intersection between the prisms. Show correct visibility of lines. Draw the development of the surfaces on another sheet.

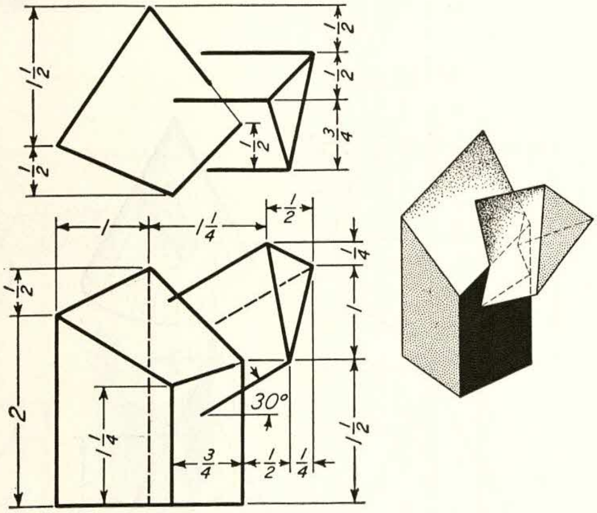
16-3 to 16-8. Find the line of intersection between the objects shown. Show correct visibility of lines. The developments are to be shown on another sheet.



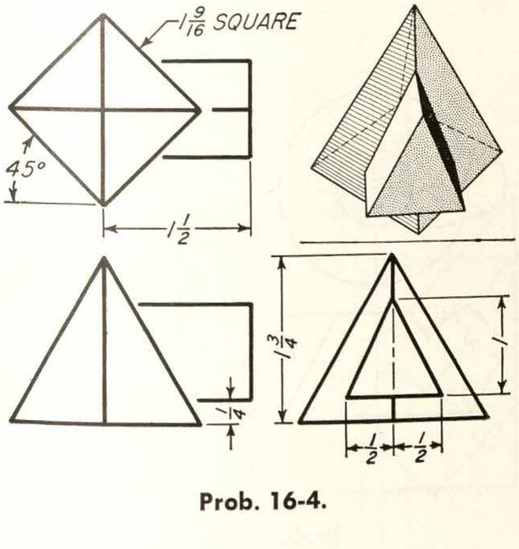
Prob. 16-1.



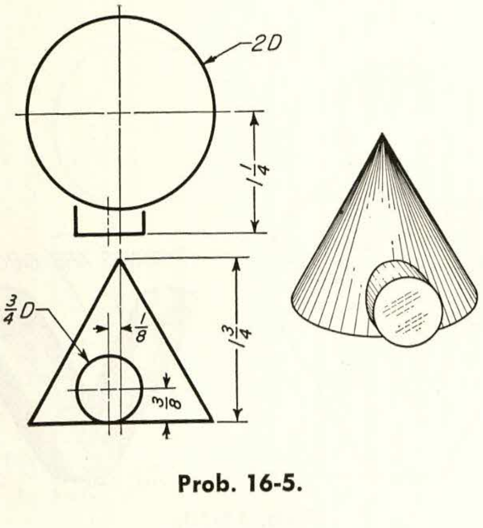
Prob. 16-2.



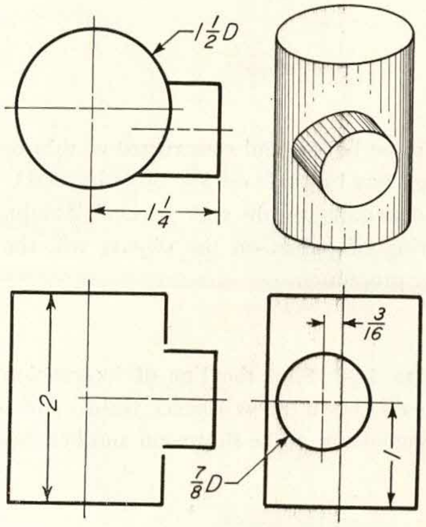
Prob. 16-3.



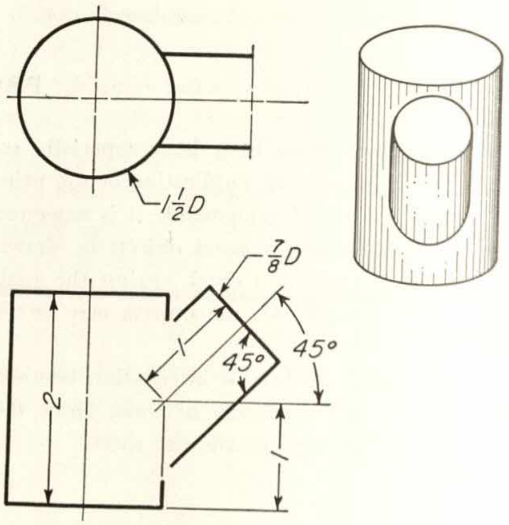
Prob. 16-4.



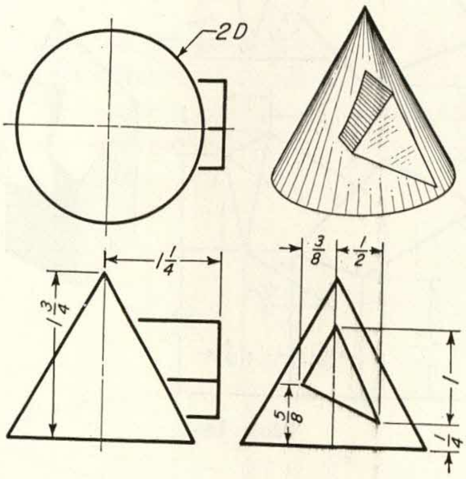
Prob. 16-5.



Prob. 16-6.

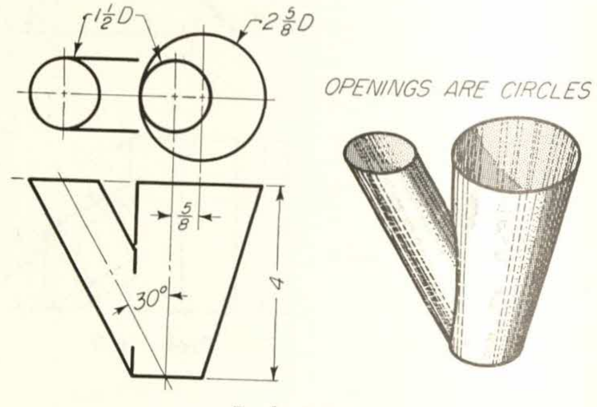


Prob. 16-7.

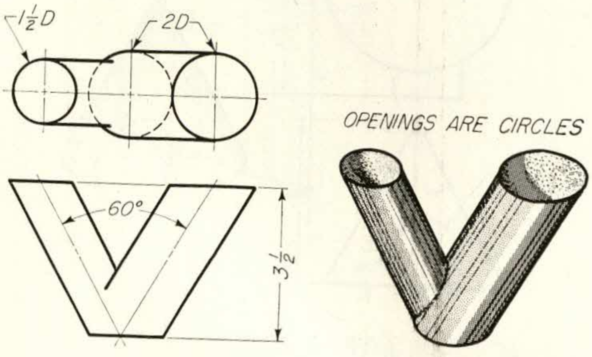


Prob. 16-8.

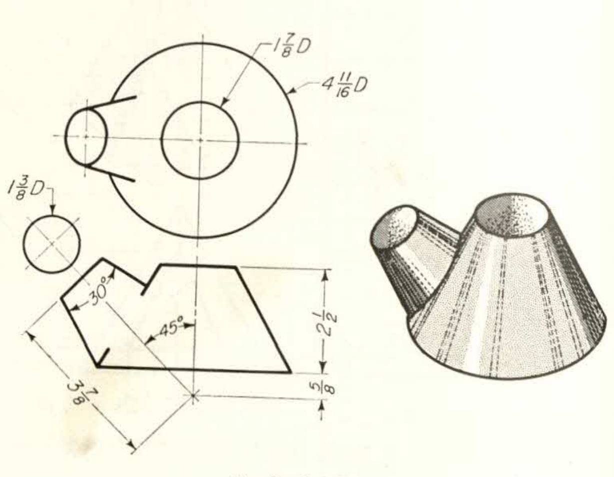
16-9 to 16-11. Show the line of intersection of the given transition pieces. Show the developments on the same sheet. Sheet size, 11 by 17 in.



Prob. 16-9.

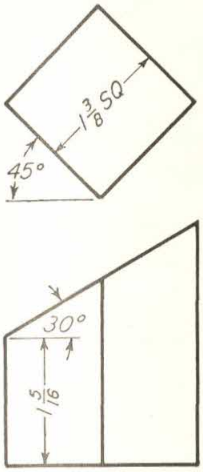


Prob. 16-10.

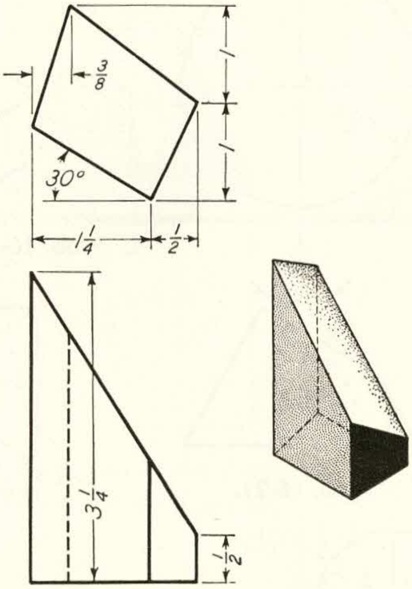


Prob. 16-11.

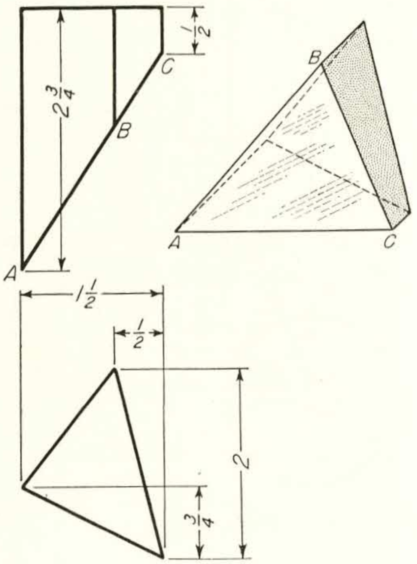
16-12 to 16-21. Develop the lateral surfaces of the given objects.



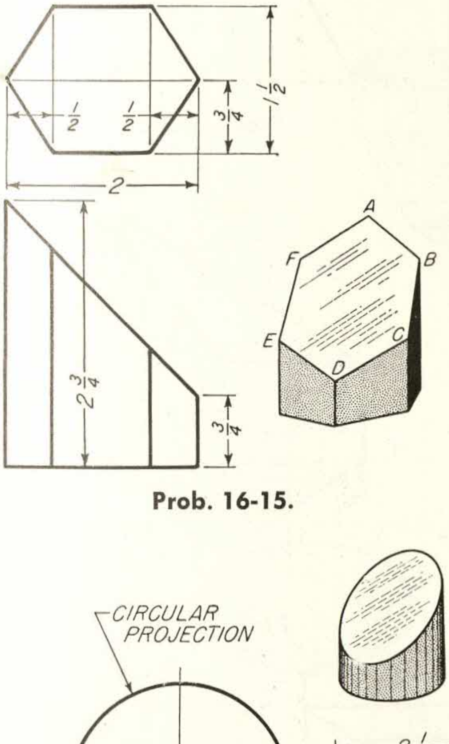
Prob. 16-12.



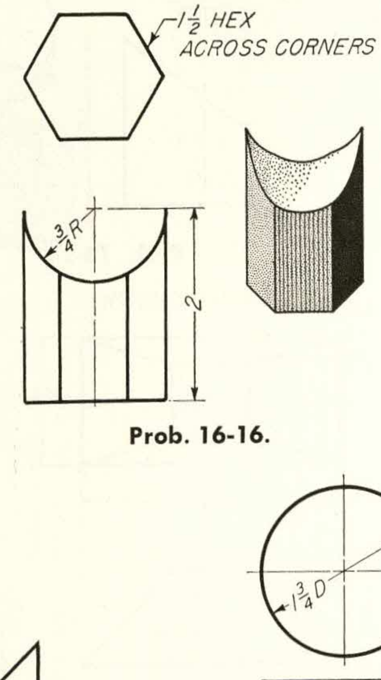
Prob. 16-13.



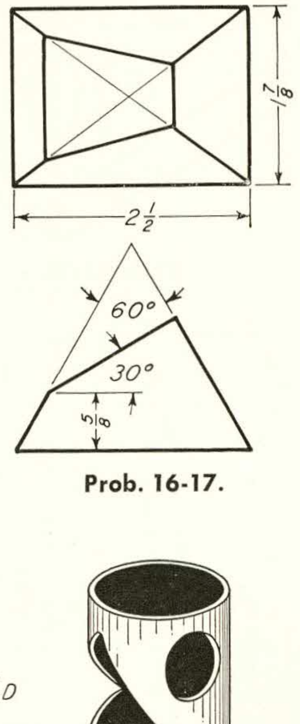
Prob. 16-14.



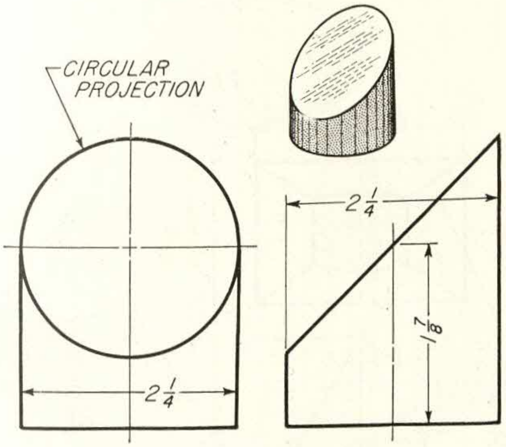
Prob. 16-15.



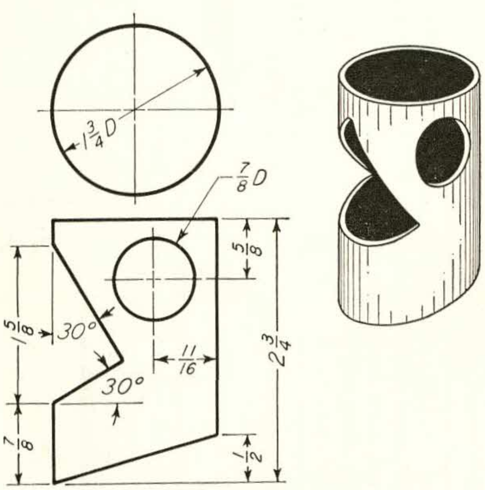
Prob. 16-16.



Prob. 16-17.

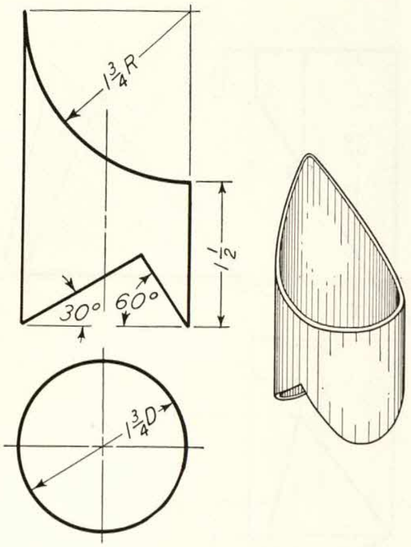


Prob. 16-18.

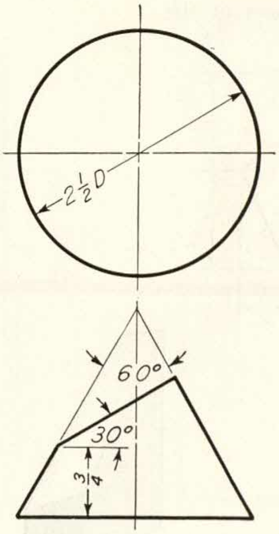


Prob. 16-19.

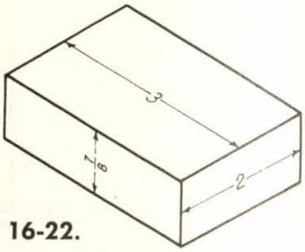
16-22 to 16-31. Develop all surfaces of the given objects.



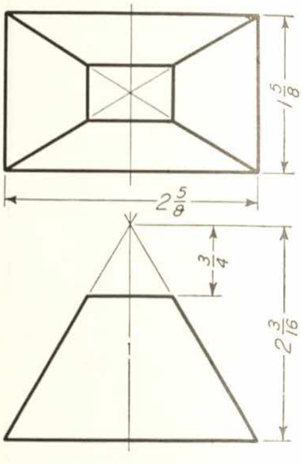
Prob. 16-20.



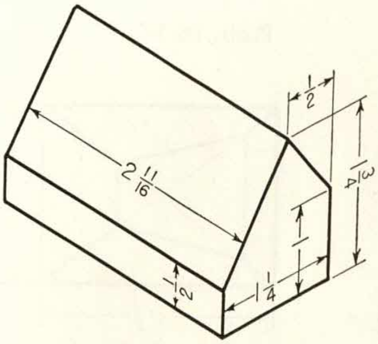
Prob. 16-21.



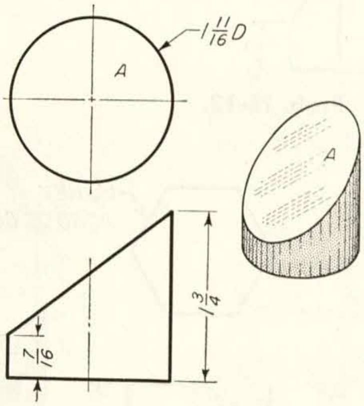
Prob. 16-22.



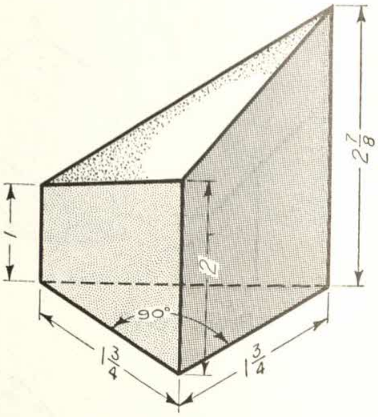
Prob. 16-25.



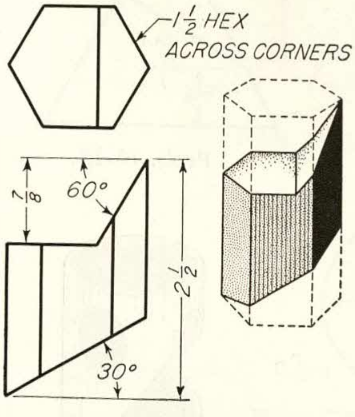
Prob. 16-23.



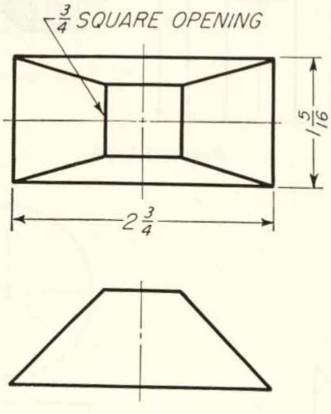
Prob. 16-24.



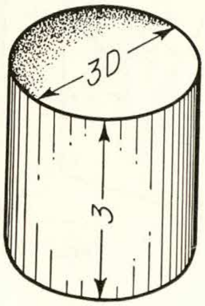
Prob. 16-28.



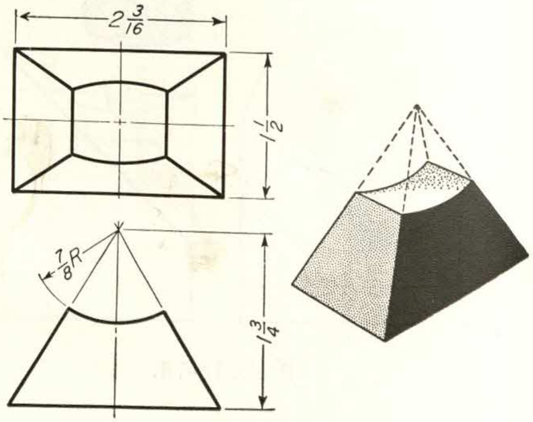
Prob. 16-26.



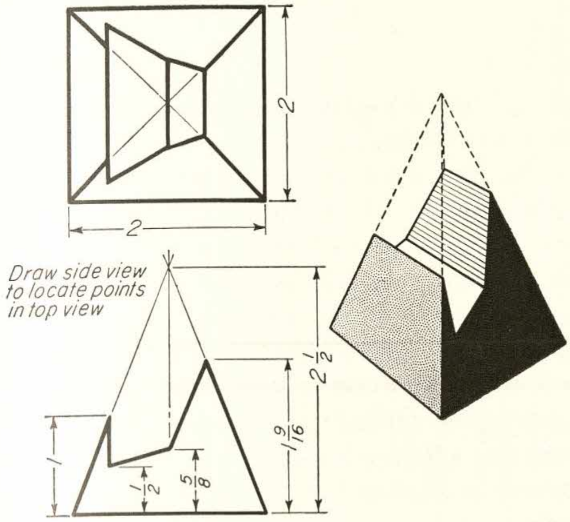
Prob. 16-27.



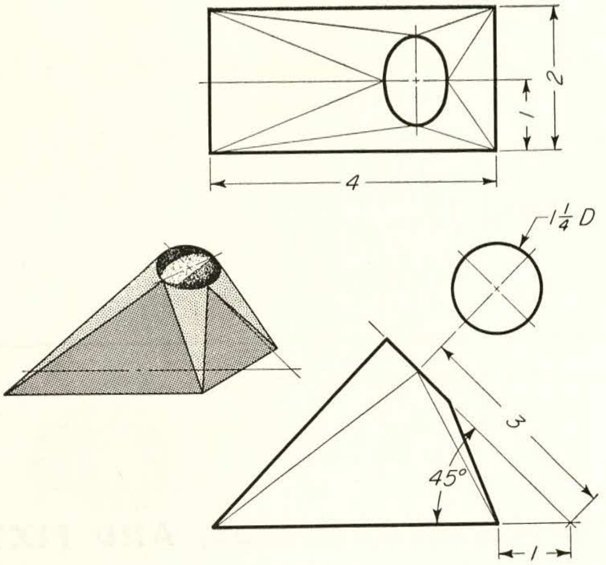
Prob. 16-29.



Prob. 16-30.

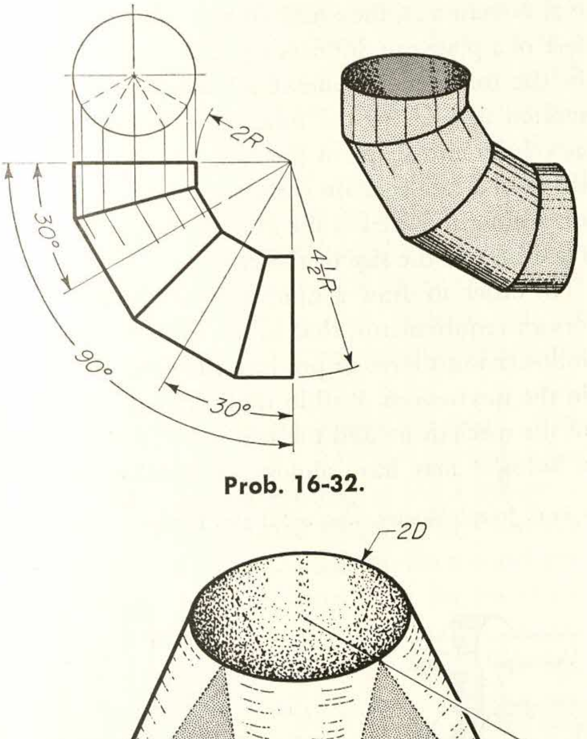


Prob. 16-31.



Prob. 16-34.

16-32 to 16-37. Show the developments of the given transition pieces. Use a suitable standard sheet size for each pattern.



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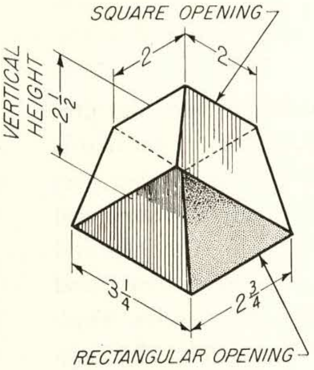

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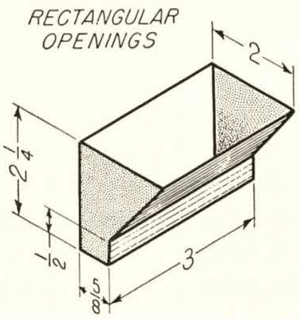
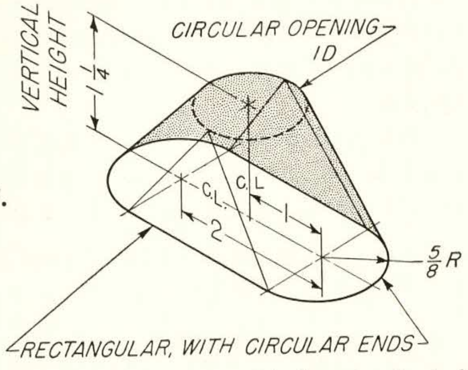


Prob. 16-36.



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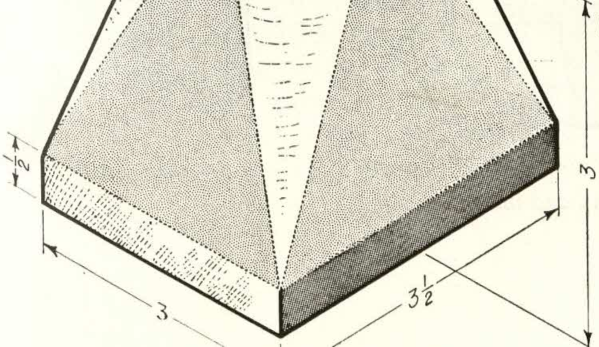

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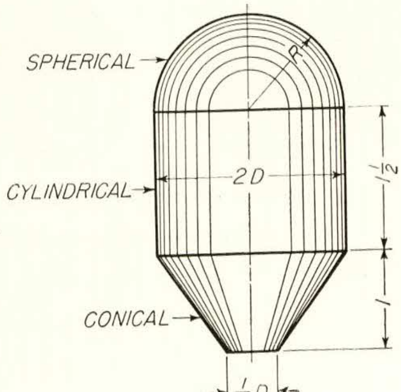
16-38. Develop the conical, cylindrical, and spherical shapes that form the surface of the vessel. Sheet size is 11 by 17 in.



Prob. 16-38.

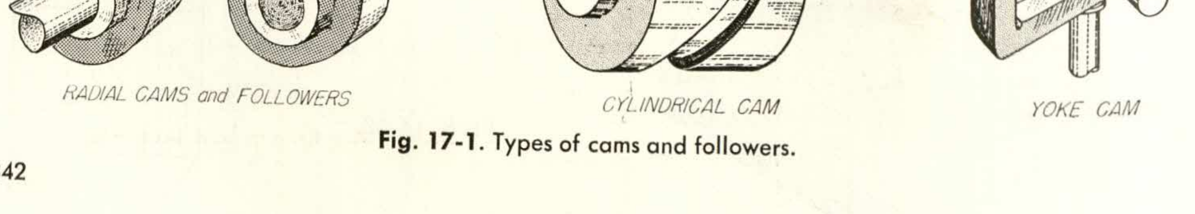
Chapter 17

CAMS, GEARS, JIGS, AND FIXTURES*

17-1. Cams. A cam is a machine part that produces a continuously repeated rotary motion that is passed on by means of a "follower" to another part of the mechanism as an automatically repeated and timed motion or operation. Cams are fundamental units of automatic machines, such as stamping and shoe machines, screw machines, and engines. Typical cams and followers are shown in Fig. 17-1. Figure 17-2 shows a typical cam unit of an internal-combustion engine with an irregularly shaped plate cam mounted on a shaft and a reciprocating valve held in continuous contact with the cam by a spring.

17-2. Cam motions. The path of the motion of the follower lies in a plane perpendicular to the axis of the camshaft if the cam is a disk, plate, or lever. When the cam is cylindrical, the follower moves in a plane parallel to, and in the same general direction as, the camshaft axis. The curved surface of a plate cam induces a predetermined motion in the follower. In almost all machine parts, the motion desired for the follower controls the characteristics and shape of the cam. Provided that the shape of a cam remains constant, however, the *kind* of motion imparted to the follower will be the same regardless of the size of the cam.

In order to draw a cam, we must first know its design requirements, that is, the sort of motion the follower must have to produce the desired motions in the mechanism. Within the inherent limitations of the mechanism and the method of manufacture, a follower may have almost any motion. Some of



RADIAL CAMS and FOLLOWERS

CYLINDRICAL CAM

YOKE CAM

Fig. 17-1. Types of cams and followers.

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* In this chapter, the material on jigs and fixtures was written by Prof. Joseph Shigley, who aided also in the revision of the portion on cams and gears.

the motions obtainable are defined by natural laws and have definite names; others are dictated by the method by which the cam is machined and cannot be classified. A graphical representation of the movement of the follower is known as a *cam-curve,* or *displacement, diagram;* and when the follower motion is defined by a natural law, it is frequently desirable to construct such a diagram before drawing the cam. If the shape of the cam is specified by the machining operations, then the displacement diagram cannot be constructed until the cam drawing is complete. The classified motions in common use are as follows:

Uniform motion, or constant velocity, is represented by a straight line in which the follower travels (or rises) equal distances in equal time intervals.

Constant acceleration is fundamentally the same motion as that of a freely falling body, where the velocity increases with the distance traveled. Decelerated motion is the exact opposite of acceleration and is often used to bring the follower to a gentle stop just before it reaches a period in which the position of the follower remains unchanged. This is called "a period of dwell" (see Fig. 17-6). Accelerated and decelerated motions used together are commonly known as gravity motion.

In simple harmonic motion, the maximum velocity is reached at the mid-point of the travel, with the velocity being zero at both ends. It may be likened to the swing of a pendulum obeying the trigonometric sine law.

17-3. Drawing a single-motion diagram. *Constant velocity, Fig. 17-3a.* On the ordinate (the vertical scale), lay off the rise of the follower to either the true or a scaled height. When suitable, the true height should be used. Divide the ordinate into a number of equal parts (six, for instance). Select a convenient length (horizontally) for the abscissa (which shows the position of the cam), and divide this into the same number of parts. As the cam moves through one unit of rotation, the follower rises one unit. The straight line of motion produced may be modified at the initial and final points of the motion to provide for smoother movement. The cam curve on the diagram is modified by striking an arc equal to one-third the follower rise at the beginning and final periods, as illustrated.

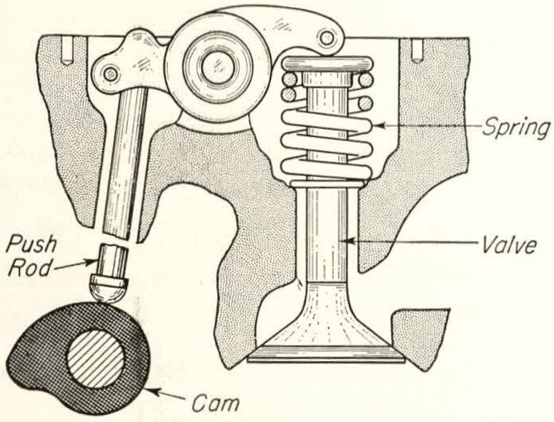
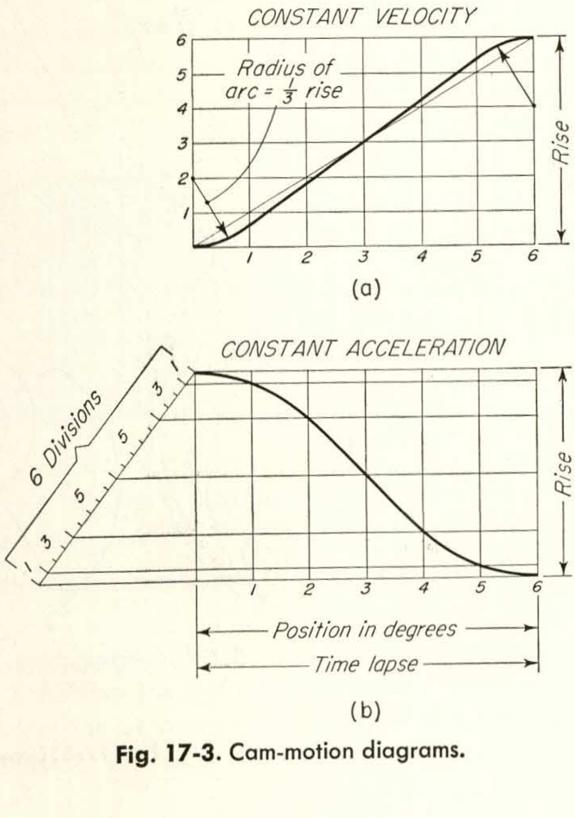


Fig. 17-2. Typical cam-unit assembly.

Constant acceleration and deceleration, Fig. 17-3b. In the diagram, the lines representing the rise, or travel, and the cam position are divided into the same number of parts. However, since the distance traveled is proportional to the square of the time, the follower rise is made proportional in increments of 1, 3, 5, 7, 9, etc. Note that the change in velocity occurs at the mid-point of the curve of the motion, and the increments are reversed at this position.

Harmonic motion, Fig. 17-4. The plotting of harmonic motion (sine curve) is shown in Fig. 17-4. The diameter of the semicircle represents the



(a)

(b)

Fig. 17-3. Cam-motion diagrams.

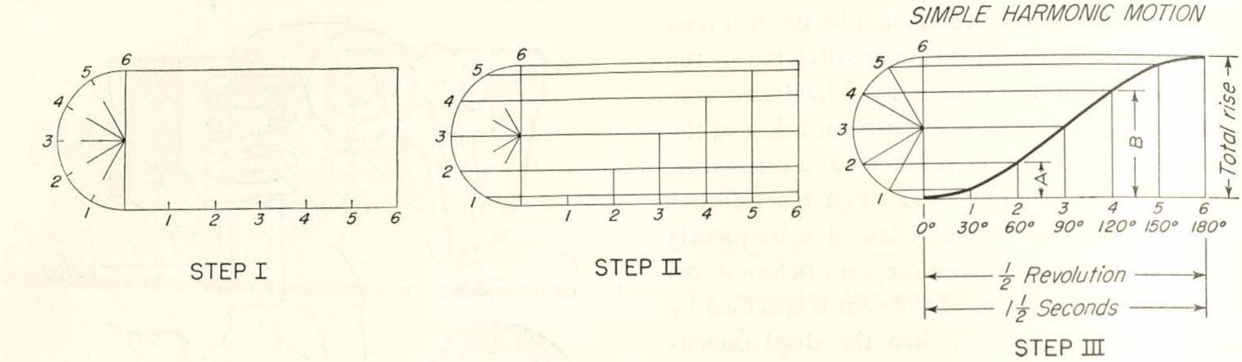


Fig. 17-4. Drawing the cam-motion diagram.

rise of the follower during this motion. Divide the semicircle and the base line into the same number of parts, as shown in Step I. Project the divisional points to their intersections (Step II). With a french curve, draw a line through the intersections to show the follower motion, as shown in Step III. This motion is the one used in the drawing of the cam curve in Fig. 17-5.

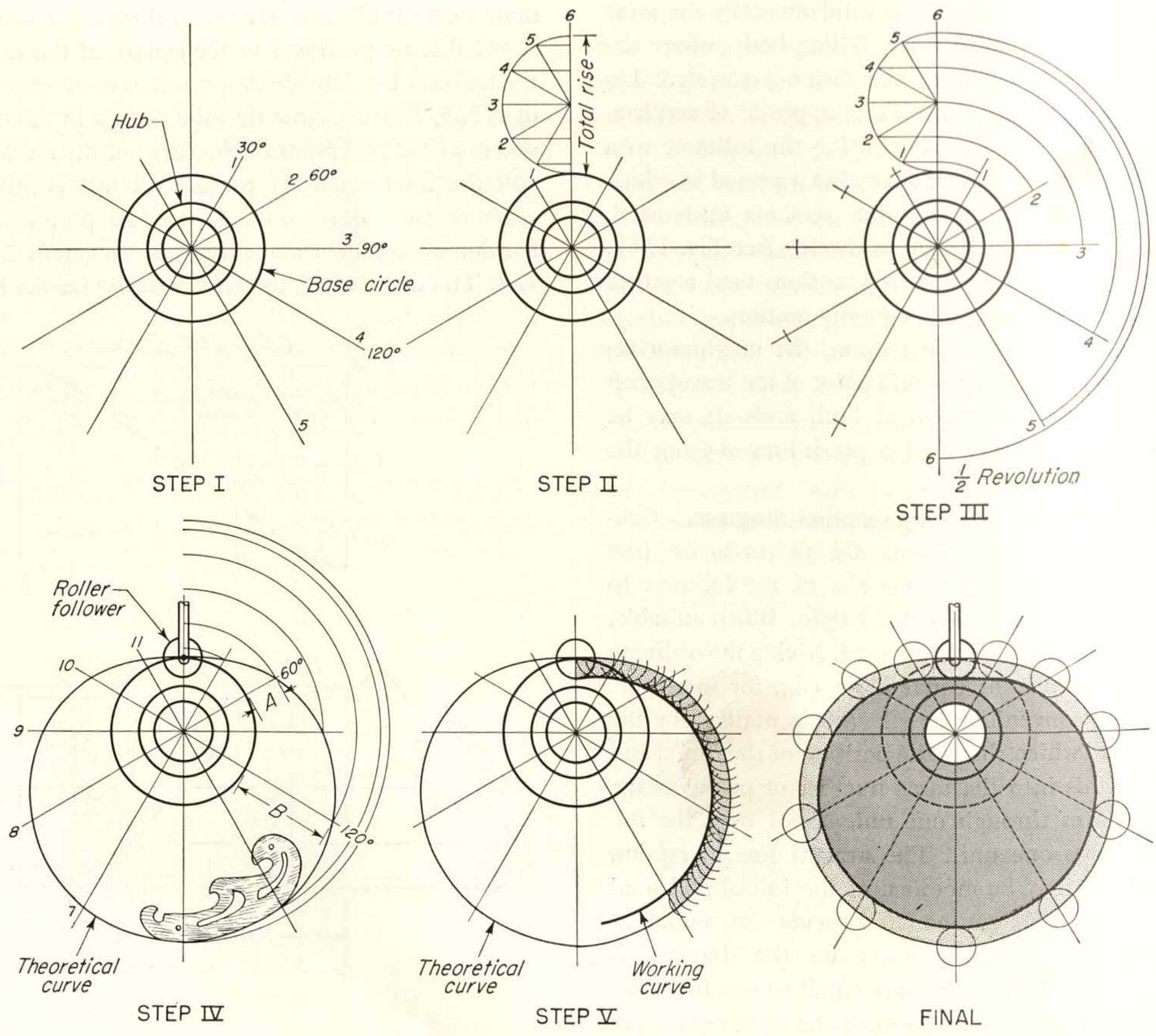


Fig. 17-5. Drawing a plate-cam curve.

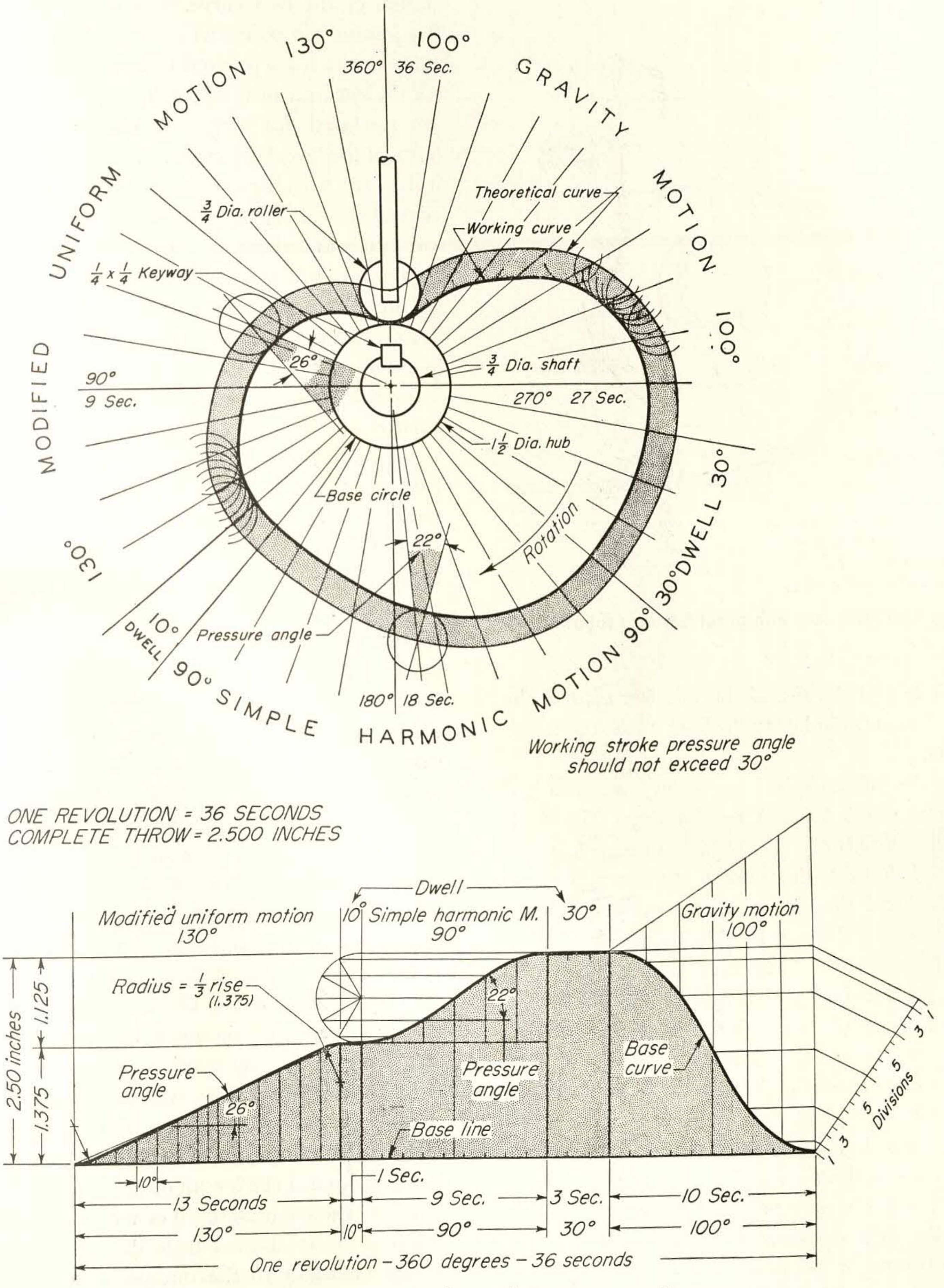


Fig. 17-6. Cam-curve outline with its cam-curve diagram.

17-4. Drawing a plate-cam curve. The principle involved in the drawing of the cam curve shown in Fig. 17-5 is the same for all types of plate cams (see Fig. 17-6, for example). First draw the circle representing the largest diameter of the hub. Then draw the base circle, the radius of which indicates the nearest approach of the theoretical cam curve to the center of the camshaft. The size of the

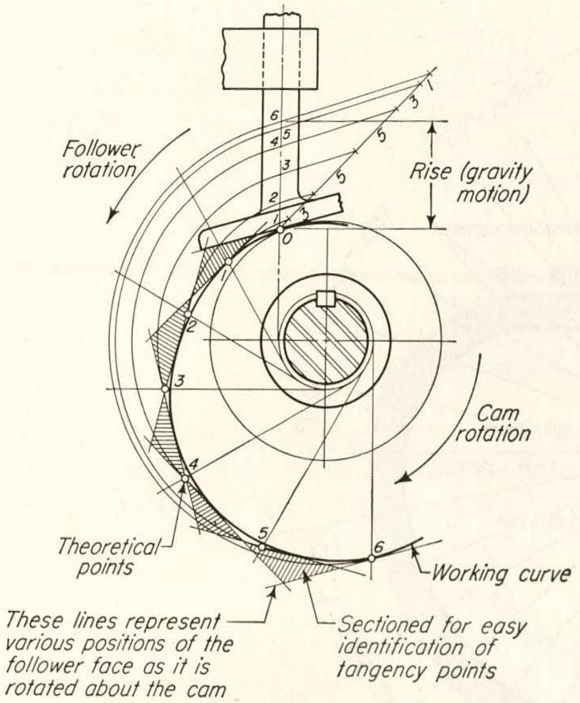

Follower rotation
6
5
4
3
2
1
0
Rise (gravity motion)
2
3
4
5
6
Cam rotation
Theoretical points
Working curve
These lines represent various positions of the follower face as it is rotated about the cam
Sectioned for easy identification of tangency points

Fig. 17-7. Flat cam with offset flat-face follower.

base circle and the rise of the follower control the size of the cam; the larger the base circle, the larger the cam.

After the hub and the base circles have been laid out, draw radial lines at regular degree intervals through the shaft center, as shown in Step I. These radial lines indicate the rotation of the cam in terms of degrees and time lapse. If the cam curve is designed from a single cam motion, as in this case, the simplest procedure is to transfer the rise to the position of the follower and project by revolving the positions of the follower as it rises (points 1 to 6) to the related degree and time-lapse positions on the radial lines, as shown in Steps II and III. Since this cam revolves one-half turn with this motion and finishes the cycle with the same motion, to complete the drawing of the theoretical cam curve, it is only necessary to project the points showing the follower in contact with the cam to the remaining radial lines in reverse order.

The points could have been transferred directly from the motion diagram to the radial lines with dividers if desired. Note that distance *A* located on line 2 at 60° on the diagram of Fig. 17-4 checks in length and position on the radial of the cam curve shown in Fig. 17-5. Distance *B* is located on 4 at 120° in both the diagram of Fig. 17-4 and the radial of the cam curve. The cam outline formed by joining the points with a french curve would be that used with a pointed follower, and it is known as the theoretical curve. When adapted to a roller or flat-faced follower, the change in design is termed the "working curve." When the follower is a roller, the working curve is developed by describing arcs of the roller radius from points on the theoretical curve and drawing the working curve tangent to the arcs (Step V). The heavily shaded portion in Step VI shows the cam shape for a roller follower, and the lighter portion shows the shape for a pointed follower.

Regardless of the kind of follower or its position relative to the cam, the same procedure is always used. To summarize, rotate the follower around the cam in a direction opposite to the cam rotation. Draw a portion of the follower at each selected position around the cam, in the correct radial position it should occupy. When enough positions have been constructed, the working curve is drawn tangent to all of them.

17-5. Pressure angle. The pressure angle is the angle that the follower makes with the cam on the pressure stroke of the cycle. Although the pressure angle varies during the various stages of the cycle, for maximum efficiency the pressure angle should be in the neighborhood of 30°. The pressure angle is measured on the cam outline between a perpendicular drawn through the point of tangency of the follower with the cam and a center line drawn through the follower stem (see Fig. 17-6). It is usually indicated at the mid-point of a working-stroke motion on the displacement diagram. As noted above, in laying out a displacement diagram consisting of one or several motions, the complete rise of the follower is drawn full scale (where possible), and the base line is drawn to any convenient length. However, if the rise of the follower is shown full scale and if the length of the base line is drawn equal to the circumference of a circle whose radius is equal to the distance from the center of the axis of the camshaft to the mid-point of the follower rise, the resulting diagram represents the true development of the pitch surface of the cam.

The cam outline shown in Fig. 17-6 for a roller follower was prepared from the displacement diagram placed below it. This figure illustrates many of the graphic techniques required in the preparation of cam drawings.

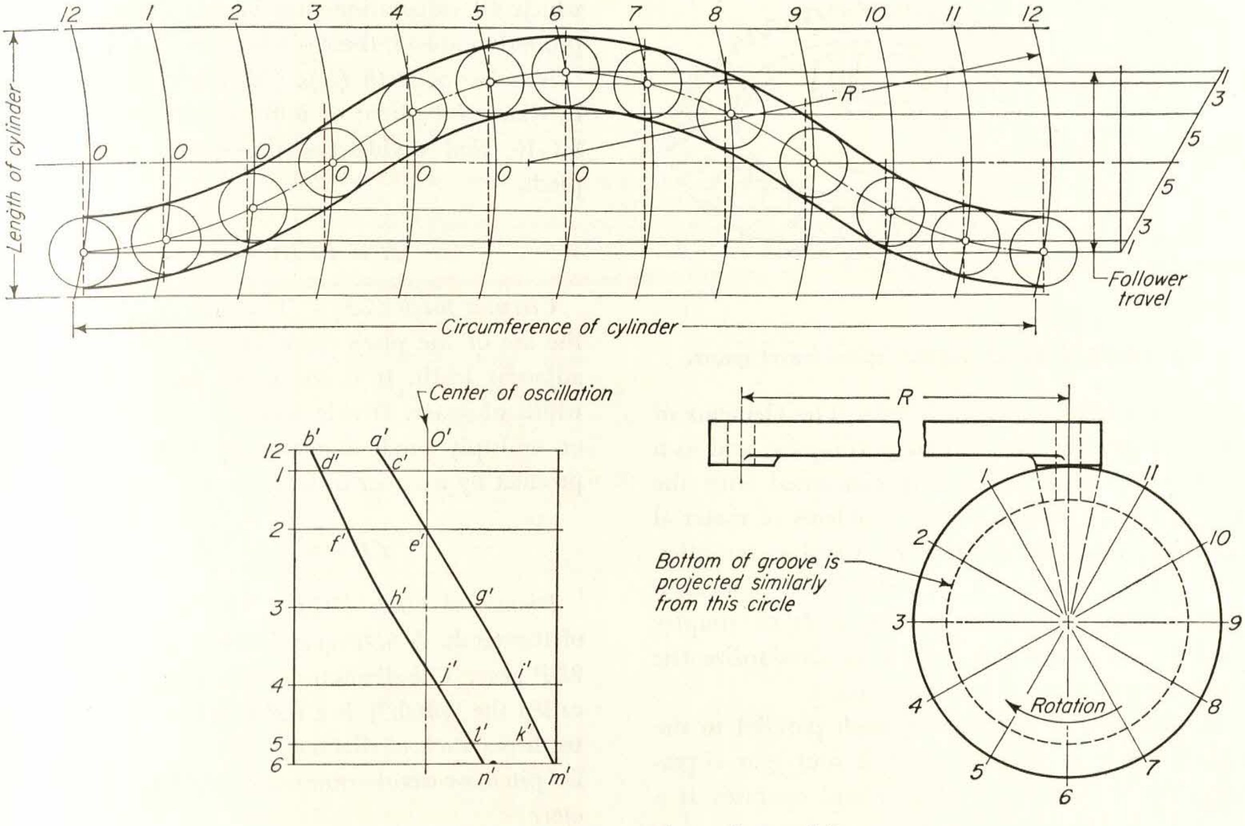
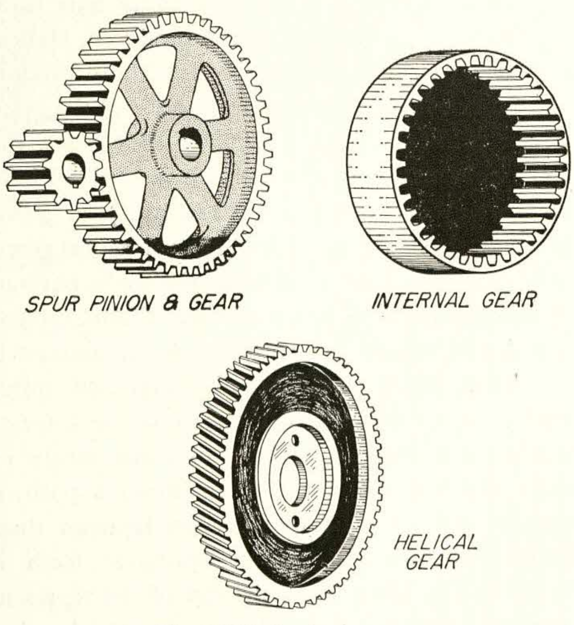


Fig. 17-8. Cylindrical cam with oscillating follower.

The construction for an inclined flat-face follower is shown in Fig. 17-7. It is seen that the flat face is constructed in the correct radial position at each selected point during the imagined rotation of the follower about the cam. If the follower is an oscillating flat-face type, then the circle representing the successive centers of oscillation must also be constructed. This is also true when the follower is an oscillating roller type.

Figure 17-8 is typical of the graphical procedure required for the construction of a cylindrical cam. The cam groove is laid out on the developed surface of the cam and transferred to the cam by projection. Although the figure illustrates an oscillating follower, the method is quite similar for a reciprocating follower.

17-6. Cam cutting. Face, peripheral, and cylindrical cams of ordinary size may be cut by outlining the cam curve on the metal blank, drilling holes around the outside of the outline, breaking off the excess metal, and filing to the outline. Cams may also be cut directly on milling machines with the aid of special attachments known as indexing mechanisms.


SPUR PINION & GEAR

INTERNAL GEAR

HELICAL GEAR

Fig. 17-9. Typical gears.

17-7. Gears. The prime function of gears is to transmit rotary motion uniformly from one shaft to another. Gears are made by casting or cutting cast and forged steel, cast-iron alloys, bronze, brass, or impregnated fabrics and fibers. Figure 17-9 illus-

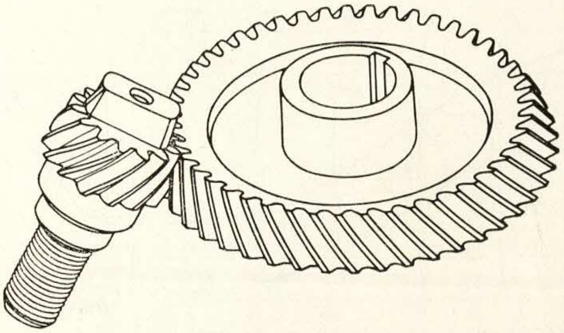


Fig. 17-10. A set of angular spiral bevel gears.

trates a number of typical gears. The elements of gear design are extraordinarily complex, and as a rule the draftsman is rarely concerned with the design requirements or with problems of material selection, strength, fatigue, or wearing qualities. Also the recent adoption of simplified design calculations requiring fewer cutting tools or simpler casting procedures has helped to standardize the drafting procedure that is followed.

A spur gear is one having teeth parallel to the axis of the gear (Fig. 17-9). The spur gear is perhaps the simplest type of gear and operates at a very high efficiency but becomes noisy at high speeds.

If the teeth are cut at an angle to the axis (usually 15° to 45°), a helical gear is produced. Helical gears may be run at higher speeds without producing as much noise as spur gears because of the gradual engagement of the teeth. For spur gears, the shaft axes must be parallel; this is not true of helical gears. Worm gears (Fig. 17-17), bevel gears, spiral bevel gears (Fig. 17-10), crossed helical gears, and hypoid gears are used when the shafts have an angular relationship to each other. Worm, crossed helical, and hypoid gears are used for nonintersecting shafts, while straight-tooth bevel and spiral bevel gears are used when the axes intersect. Gears have an advantage over belts or other means of power transmission, for they maintain a positive constant average ratio of velocities between their shafts. The nomenclature of spur-gear teeth is shown in Fig. 17-11. A knowledge of the representation of a spur gear is fundamental to the drawing and detailing of any type of gear.

17-8. Gear terms and formulas. In discussing and drawing gears, the following terms and formulas will be used:

Pitch circle. This is a theoretical circle upon which all calculations are based. When gears are properly meshed, their pitch circles are tangent.

Number of teeth (*N*). Multiply pitch diameter by diametral pitch; or multiply pitch diameter by 3.1416, and divide the product by the circular pitch.

$$N = PDDP = \frac{PD\pi}{CP}$$

Circular pitch (*CP*). The distance measured on the arc of the pitch circle between like points on adjacent teeth. It is the tooth thickness plus the width of space. Divide 3.1416 by diametral pitch; or multiply pitch diameter by 3.1416 and divide product by number of teeth.

$$CP = \frac{\pi}{DP} = \frac{\pi PD}{N}$$

Diametral pitch (*DP*). This indicates the size of the teeth. A 4*DP* gear has larger teeth than an 8*DP* gear. The diametral pitch (sometimes simply called the "pitch") is a ratio giving the number of teeth per inch of diameter. Divide 3.1416 by circular pitch, or divide number of teeth by pitch diameter.

$$DP = \frac{\pi}{CP} = \frac{N}{PD}$$

Pitch diameter (*PD*). Diameter of pitch circle. Divide the number of teeth by diametral pitch; or multiply the number of teeth by circular pitch, and divide product by 3.1416.

$$PD = \frac{N}{DP} = \frac{NCP}{\pi}$$

Center distance (*CD*). Distance between the centers of two gears in mesh. Add the number of teeth in gear and pinion, and divide the sum by twice the diametral pitch; or multiply the sum of the number of teeth in the gear and pinion by circular pitch, and divide the product by 6.2832.

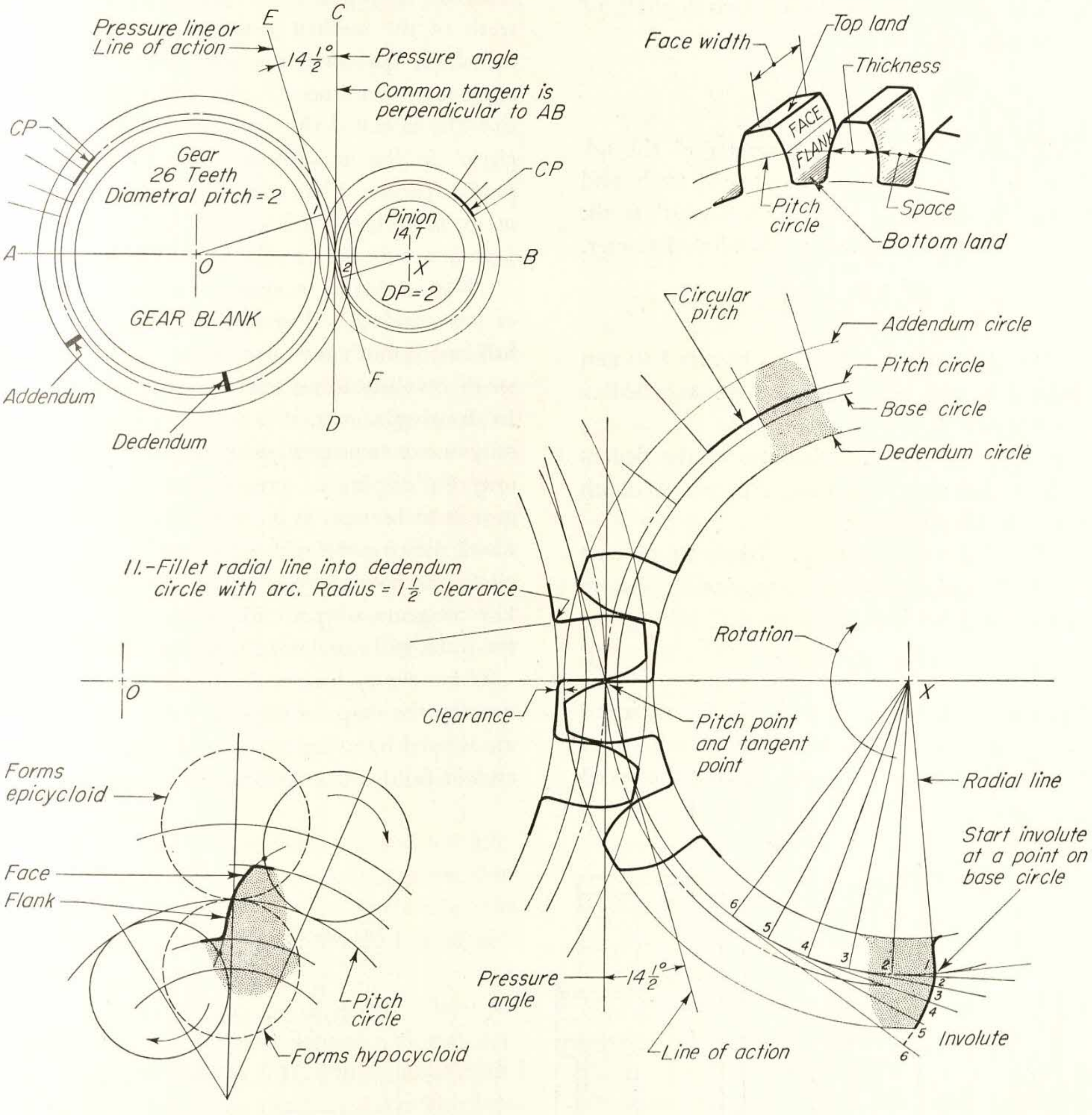
$$CD = \frac{N_g + N_p}{2DP} = \frac{(N_g + N_p)CP}{6.2832}$$

Addendum (*A*). The radial distance from the top land of tooth to pitch circle. Divide 1 by the diametral pitch, or divide circular pitch by 3.1416 (for full-depth teeth).

$$A = \frac{1}{DP} = \frac{CP}{\pi} \quad \text{(full-depth teeth)}$$

$$= \frac{0.8}{DP} \quad \text{(stub teeth)}$$

1.- Draw pitch circles tangent on AB.
2.- Draw common tangent CD.
3.- Draw line of action EF through common tangent point.
4.- Draw perpendiculars from O and X to EF intersecting at 1 and 2.
5.- Draw base circles with radii O1 and X2.
6.- Draw addendum circle from calculations.
7.- Draw dedendum circle from calculations.
8.- Divide pitch circle of gear into 26 equal parts and that of pinion into 14 (for circular pitch).
9.- Bisect circular pitch on gear and pinion (no allowance for backlash). CP=Thickness plus space.
10.- Develope involute for shape of teeth (portion between base and addendum circles). Draw radial line from base circle to dedendum circle to complete flank.



For construction see chapter V

Fig. 17-11. Drawing a spur gear and pinion.

Clearance (*C*). Radial distance from the top land of a given tooth to the bottom land of the mating tooth space. Divide 0.157 by the diametral pitch (for standard full-depth teeth).

$$C = \frac{0.157}{DP} \quad \text{(full-depth teeth)}$$
$$= \frac{0.200}{DP} \quad \text{(stub teeth)}$$

Dedendum (D). Radial distance from the pitch circle to the bottom land. The addendum plus the clearance.

$$D = \frac{1.157}{DP} = A + C \text{ (full-depth teeth)}$$
$$= \frac{1.200}{DP} = A + C \text{ (stub teeth)}$$

Circular thickness (CT). Thickness of tooth on pitch circle. Divide 1.5708 by diametral pitch, or divide circular pitch by 2.

$$CT = \frac{1.5708}{DP} = \frac{CP}{2}$$

Outside diameter (OD). Diameter of the addendum circle. Add 2 to the number of teeth, and divide sum by diametral pitch for full-length teeth; or add 2 times the addendum to the pitch diameter.

$$OD = \frac{N + 2}{DP} = 2A + PD$$

Whole depth (WD). Radial distance between the dedendum and addendum circles. Add dedendum to addendum.

Root diameter (RD). Diameter of the dedendum circle. Subtract two times the whole depth from the outside diameter.

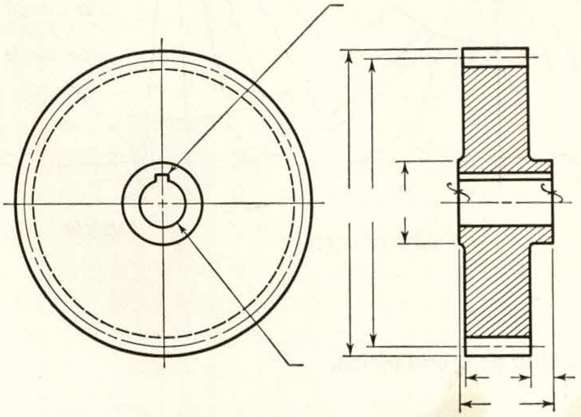
Base-circle diameter (BCD). Diameter of base circle. Multiply pitch diameter by cosine of pressure angle. Use same for internal gears.

$$D_b = PD \cos A$$

17-9. Tooth standards. A perfectly designed gear tooth is shaped in a way that permits it to travel through the meshing cycle so that the speed of the driven gear will not vary in the slightest. One curve for this shape that fulfills this condition and is easily reproduced by modern methods of manufacturing is the *involute curve* (see Chap. 5). In order to differentiate between the various types of involute teeth, it is necessary to define the terms *base circle, pressure angle,* and *pressure line,* or *line of action.* See Fig. 17-11. Line *EF,* which represents the direction of the forces operating on the teeth of the meshed gears during engagement, is called the "pressure line," or "line of action." The angle between line *EF* and the common tangent line *CD* is called the "pressure angle." The "base circle" is the generating circle for the involute-profile curve. When drawing a pair of gears in mesh, their base circles (radii *O*-1 and *X*-2 in the figure) are tangent to the pressure line (*EF*).

17-10. Drawing a spur gear. The three more or less standardized gear-tooth forms are the 14½° full-length-tooth involute form, the 20° full-depth-tooth involute form, and the 20° stub-tooth form. In drawing a gear, it is usually necessary to show only one or two teeth; gears are toothed completely only for display or presentation drawings. If the gear is to be cast, it is necessary to draw only the blank showing the addendum circle, the dedendum circle, the base circle, and the outline of one tooth. For cut gears, only the blank and notes concerning the pitch and number of teeth need be given.

Either the cycloid or the involute may be used to develop the shape of the gear tooth. Gear teeth that are shaped by using portions of the involute or the cycloid fulfill the requirements of the fundamental



NO. OF TEETH	
DIAMETRAL PITCH	
TOOTH FORM	
WHOLE DEPTH	
CHORDAL THICKNESS	
CORRECTED ADDENDUM	

CUTTING DATA

COMPLETE AND SHOW CHART ON DRAWING

Fig. 17-12. Dimensioning and cutting data for a spur gear.

law of toothed gearing, which is a problem of design and cannot suitably be discussed here. The axes of spur gears are parallel to each other. If one of a pair of gears in mesh is much larger than the other, the smaller of the two is called the "pinion." The freedom between the teeth of two meshing gears is called *backlash* and is measured in decimal parts of an inch by a feeler gage placed between two meshed teeth when located at the tangent point of the pitch circles of both gears.

Figure 17-11 indicates a step-by-step procedure for laying out and drawing a gear and pinion. The gear has 26 teeth, the pinion has 14 teeth, the diametral pitch is 2, and the pressure angle is $14\frac{1}{2}°$. Note that the circular pitch is the same in both gears, that the gear teeth are in the shape of an involute and start at the base circle, that the base circles are between the pitch circles and the dedendum circles, and that a gear must have an integral (whole number) of teeth. The involute shape is determined by the diameter of the base circle. Involutes generated from the same diameter base circles are identical in shape, and the teeth will look the same. After the involute has been generated, use a thin sheet of clear plastic material to cut out a template for the shape of the tooth. There are methods of approximating the tooth shape by using arcs of circles, but the template method will give a more accurate tooth form and, in addition, will show if interference is present. Separate templates will have to be made for the gear and pinion. When two mating spur gears have the same number of teeth, the same template can be used to show their tooth form.

Although the contour of the flank and the fillet of a gear are formed by the generating cutter during the manufacturing process, the draftsman may use the method suggested in the illustration for producing them on a drawing.

17-11. Dimensioning a spur gear. The dimensioning of a spur gear and its required cutting data are shown in Fig. 17-12. The chordal thickness is the thickness of the tooth at the pitch circle measured in a straight line. The corrected addendum is the distance from this chord to the top of the finished tooth, measured radially. In the cutting operation, these dimensions are carefully checked with a vernier specially made for measuring gear teeth. The width of the face of the tooth may be given but is not always required. This measurement should not be confused with the width of the gear itself, which is measured on the rim parallel to the axis of the gear.

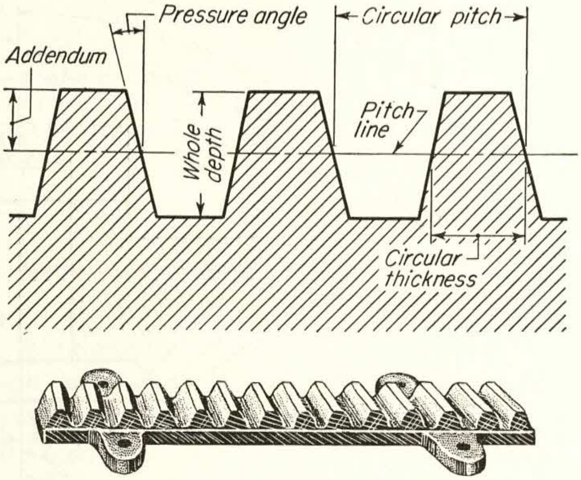


Fig. 17-13. A rack.

17-12. Internal gears. The parts of an internal gear are the same as for an external gear with the exception that an internal diameter is introduced and the outside diameter is eliminated. The addendum and dedendum merely take reverse positions from those they occupy on an external gear.

17-13. The rack. A rack (Fig. 17-13) is a straight bar with teeth in it that engage those of a spur gear. Usually the gear revolves and moves the rack in a straight line, although in some mechanisms this is reversed so that the rack motivates the gear. In designing a rack, the problem is basically one of making the teeth of such shape that the gear will transmit its motion to the rack smoothly and efficiently. The involute-tooth profile for a rack is a straight line because the base circle has an infinite radius. The pitch point of the gear is tangent to the pitch line of the rack when the two are in mesh. The thickness of the teeth, the addendum, and the depth of the teeth below the pitch line are calculated in the same manner as for the gear (see Fig. 17-11). In drawing a rack, the number of teeth, the diametral pitch, the linear pitch (equal to circular pitch of gear in mesh), and the whole depth must be specified.

17-14. Bevel gears. Straight-tooth bevel gears represent the most efficient method of transmitting power between intersecting shafts. Although most bevel gears are made for 90° shaft angles, they may

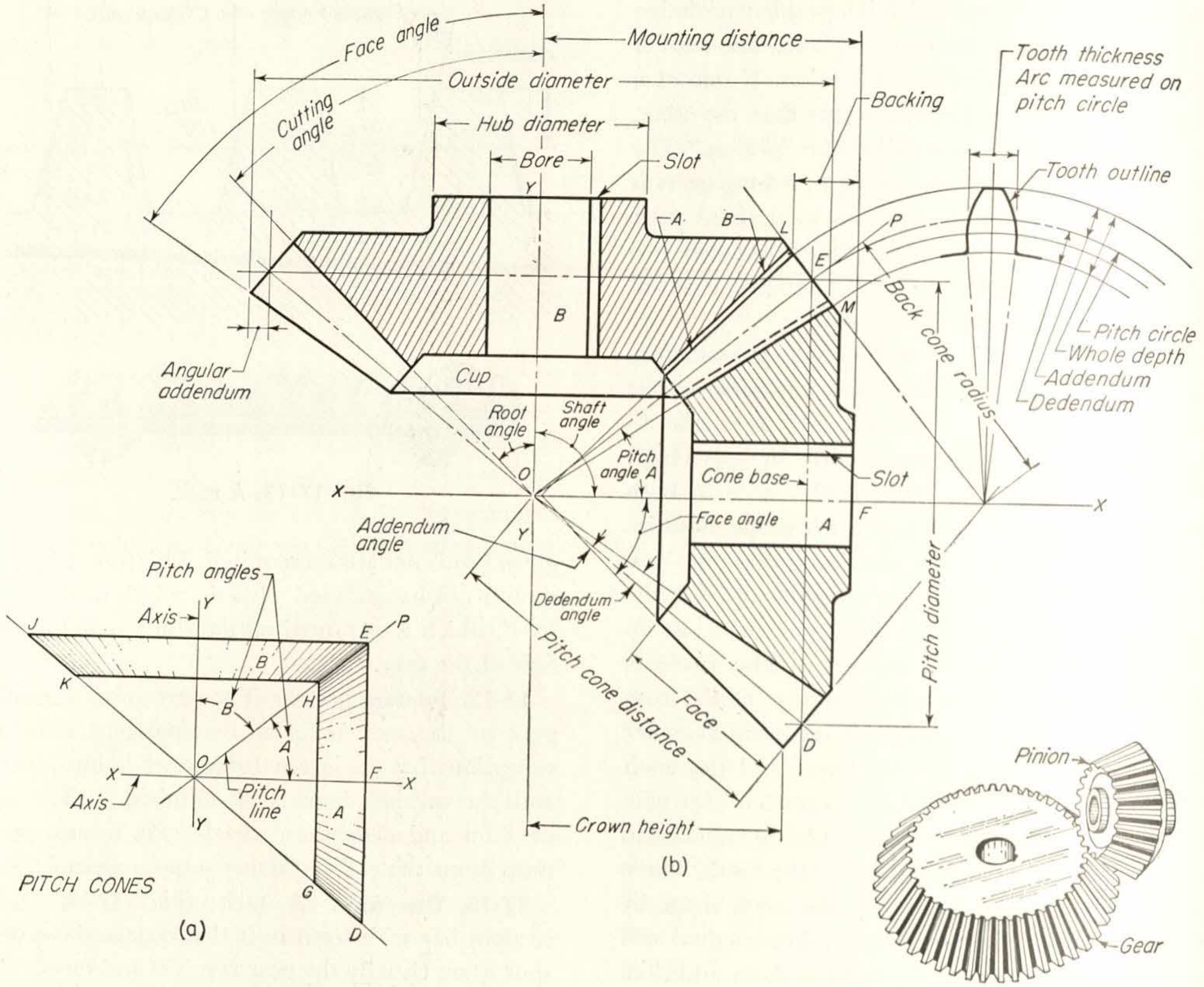


Fig. 17-14. Drawing a pair of bevel gears.

be made for almost any shaft angle. Bevel gears in mesh may be likened to a pair of cone frustums whose surfaces are tangent and whose axes intersect at a common apex.

Bevel gears are always made in pairs. They are not interchangeable with another pair having a different number of teeth even though the pitch may be the same. This makes it possible to vary the tooth form in order to obtain an optimum tooth profile as a function of the tooth number ratio.

17-15. Terms and formulas. Refer to Fig. 17-14 for the graphic representation of the following definitions and rules. The tooth dimensions for bevel gears are always specified for the large end of the tooth.

Pitch angle of pinion. Divide the number of teeth in the pinion by the number of teeth in the gear to find the trigonometric tangent of the angle.

Pitch angle of gear. Divide the number of teeth in the gear by the number of teeth in the pinion to find the tangent of the angle.

Pitch diameter. Multiply the number of teeth by the circular pitch, and divide by 3.1416; or divide the number of teeth by the diametral pitch.

Addendum. Multiply circular pitch by 0.318, or divide 1.00 by the diametral pitch.

Dedendum. Divide 1.157 by the diametral pitch, or multiply 0.368 by the circular pitch.

Whole depth of tooth space. Divide 2.157 by the diametral pitch, or multiply 0.687 by the circular pitch.

Thickness of tooth at pitch line. Divide circular pitch by 2, or divide 1.571 by the diametral pitch.

Pitch-cone radius. Divide the pitch diameter by twice the sine of the pitch angle.

Addendum angle. Divide the addendum by the pitch-cone radius to find the trigonometric tangent of the angle.

Dedendum angle. Divide the dedendum by the pitch-cone radius to find the tangent of the angle.

Face angle. Add pitch angle and addendum angle.

Cutting angle. Subtract the dedendum angle from the pitch angle.

Angular addendum. Multiply the cosine of the pitch angle by the addendum.

Outside diameter. Add the pitch diameter and twice the angular addendum.

Root angle. The angle between an element of the root cone and its axis. Cutting angle and root angle are the same.

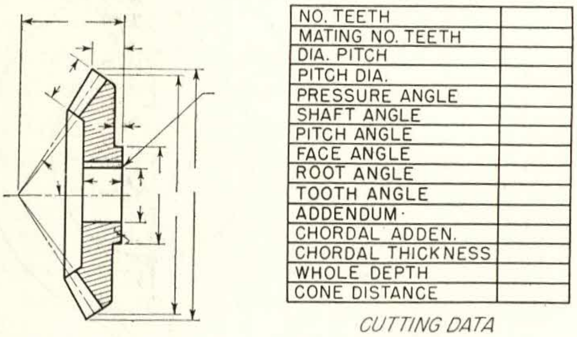
Bevel gears are sized by specifying the diametral pitch for the large end of the tooth. Theoretically, at least, the teeth must be generated from a spherical surface; but since this is not practical, the approximation shown in Fig. 17-14 (at upper right) is used. Here the tooth is laid out on the back-cone circle, which makes it the same shape as that of a spur gear having a larger radius.

The 20° pressure angle is probably the most popular at the present time, although 14½° and 17½° are also used. Bevel gears are not interchangeable, and for this reason there is no object in using interchangeable tooth forms. This makes it possible to use long- and short-addendum teeth to give better tooth action during engagement. This system uses a full-depth tooth, but the pinion uses a long addendum and the gear a long dedendum. The actual values depend upon the number of teeth on each gear and so cannot be given here. They have been published by The Gleason Company, however, and are widely available.

17-16. Drawing a pair of bevel gears. To draw a pair of bevel gears in mesh, follow the procedure outlined in Fig. 17-14.

1. Draw the axis *XX* of one of the cones, as shown in (*a*).
2. At any convenient distance draw the line *DE* perpendicular to *XX*.
3. Through any point *O* draw the line *OE* making the required pitch angle with *XX*.
4. Draw line *OD* making the same angle with *XX* to complete the pitch cone. *OE* corresponds to the pitch circle of a spur gear and is the pitch line between the two bevel gears. Distance *OE* is the pitch-cone radius. Angle *EOF* is the pitch angle of the pinion *A*.
5. To complete the drawing of the frustum of cone *A*, draw *GH* parallel to *DE* at any desired slant height, such as *EH*.
6. Through *O* draw axis *YY* making the required pitch angle with pitch line *OE* and the required shaft angle with axis *XX* of the pinion.
7. Through *O* draw *OJ* making the same angle with *YY* as *OE*.
8. From point *E* draw *EJ* perpendicular to *YY*, and from point *H* draw *HK* parallel to *EJ* to produce the frustum of the cone *B*. In revolution, *B* would revolve on its axis *YY*, *A* on its axis *XX*, and the two would come in contact along their common element, indicated by *EH*, of the pitch line *OE*. The pitch line, the pitch angles, and the gear axes are fundamental lines in the laying out of bevel gears.

From computations or directly from the given data, draw in the addendum and dedendum angles to show the tooth top lines and the tooth base lines (full depth of tooth) for both gears (see Fig. 17-14*b*). Note that, in the manufactured gear, the face of a tooth on one gear is parallel to a root-cone element of the mating tooth on the mating gear. *LM* is next drawn perpendicular to the pitch line *OE* to intersect the pitch-cone radius to give the outer edge of the tooth. The inner edge of the tooth is located from data giving the length of the tooth. The depth and clearance of the gear cup are also drawn from given data or computations. If the gear is to be cast, the tooth outline should be shown (use same method as for spur gears). If the



NO. TEETH	
MATING NO. TEETH	
DIA. PITCH	
PITCH DIA.	
PRESSURE ANGLE	
SHAFT ANGLE	
PITCH ANGLE	
FACE ANGLE	
ROOT ANGLE	
TOOTH ANGLE	
ADDENDUM·	
CHORDAL ADDEN.	
CHORDAL THICKNESS	
WHOLE DEPTH	
CONE DISTANCE	

CUTTING DATA

GIVE THESE DIMENSIONS ON THE DRAWING

COMPLETE AND SHOW CHART ON DRAWING

Fig. 17-15. Dimensioning and cutting data for a bevel gear.

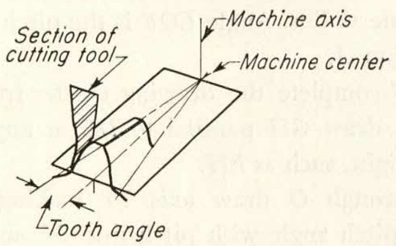


Fig. 17-16. Bevel-gear tooth angle. (The tooth angle is the angle at the machine center between the line to the center of the tooth and the line to the point of the tool.)

gear is to be cut, give the cutting data required, as shown in Fig. 17-15.

17-17. Working drawings. Figure 17-15 shows a typical working drawing for a bevel gear. Usually only one view need be constructed. The table of cutting data should be completed and shown on the drawing. The meaning of tooth angle is shown in Fig. 17-16. This angle is required for setting up the Gleason generator.

17-18. Worm and worm gears. Figure 17-17 shows an assembly drawing of a worm and a single-enveloping worm gear. The worm may also be made to wrap around the gear partially, in which case they are known as a double-enveloping worm-gear set.

A worm and worm gear in combination have the same hand of helix, but the helix angles are usually quite different. The helix angle on the worm is generally very large and that on the gear very small. Because of this, it is usual to specify the *lead angle* on the worm and the helix angle on the gear; the two angles are equal for a 90° shaft angle. The worm lead angle is the complement of the worm helix angle.

In specifying the pitch of worm-gear sets, it is customary to give the linear pitch of the worm and the circular pitch of the gear. These are equal for a 90° shaft angle. The pitch diameter of the gear is the same as for spur gears. The pitch diameter of the worm may be any value, but it should be the same as the hob used to cut the worm-gear teeth.

There is no standard for pressure angles, but, in general, large pressure angles should be used for large leads in order to avoid undercutting of the worm-gear tooth.

Worms and worm gears are specified on working

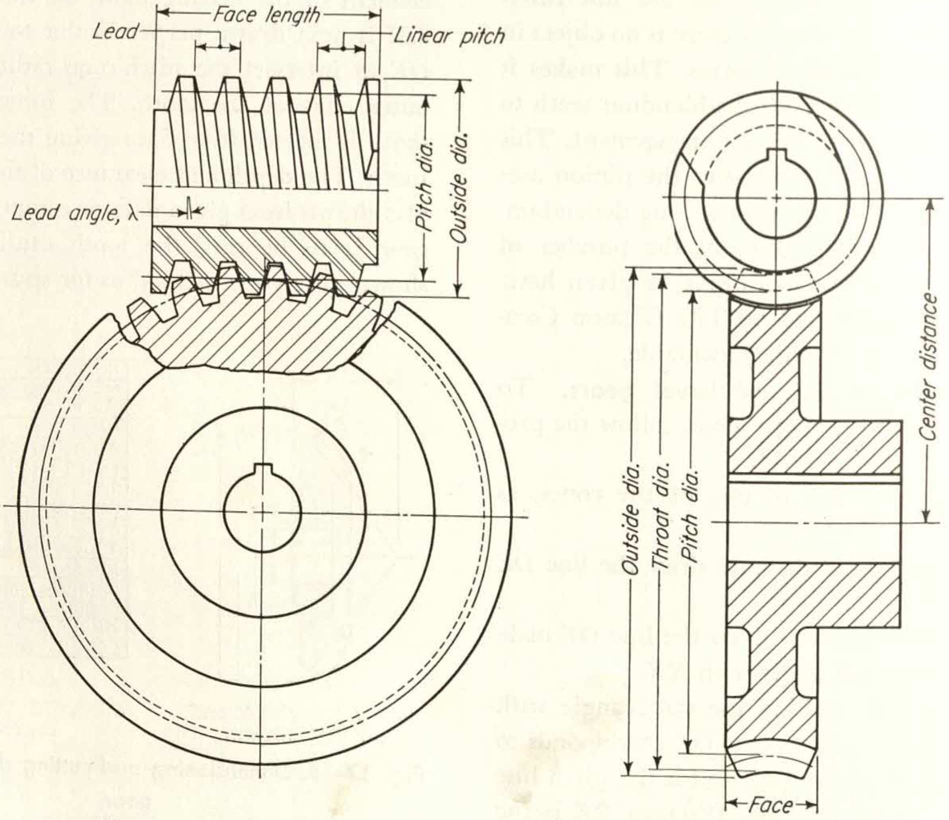
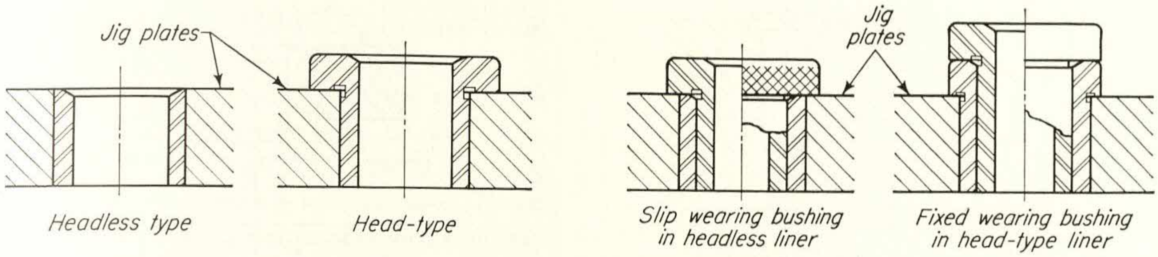


Fig. 17-17. Assembly drawing of single-thread worm and worm gear.


Jig plates
Headless type
Head-type
Jig plates
Slip wearing bushing in headless liner
Fixed wearing bushing in head-type liner

(a) PRESS FIT BUSHINGS

(b) RENEWABLE BUSHINGS

Fig. 17-18. Installation of jig bushings.

drawings in the same manner as spur gears. The table of cutting data should also contain the linear pitch, the lead angle, and the hand.

17-19. Jigs and fixtures: general. After a machine or structure has been designed by the engineer and all its parts specified or detailed by the draftsman, it is still not ready for production. The prepared drawings are routed to the tool-engineering department, where special tools necessary for the most economical procedures possible for its mass production can be designed and manufactured. The success or failure of a newly designed product often hinges upon the know-how and skill of the tooling department. This department has the function of designing the production tools best suited to utilize the lowest level of the craftsman's skill and yet achieve the highest rate of production in manufacturing interchangeable parts which will work satisfactorily in the complete machine. The greater portion of a tool designer's time is spent in designing jigs and fixtures.

Jigs and fixtures are the devices used with cutting tools to produce interchangeable parts. The workpiece may be retained or held in a certain position by either the jig or the fixture. In particular, a jig holds the workpiece but is not necessarily fastened to the cutting machine. On the other hand, a fixture is fastened (by bolting or otherwise) to the cutting machine. A drill jig, for example, may hold a workpiece that has several holes to be drilled in a certain relationship to each other; thus the jig must be capable of being moved on the drill-press table to permit alignment of each bushing under the drill spindle. A fixture bolted to the table of a milling machine makes it necessary to move the table in order to place the workpiece in the proper aligned position for cutting.

Generally, a jig or a fixture is only made once, that is, only one unit of its kind is built. Since the device must be more accurate than the workpiece, its construction requires the services of very highly skilled workmen. Thus these tools are very expensive to produce, and their designer has an opportunity to exercise his native ingenuity in creating a device which is simple, easy to produce, and yet will serve completely satisfactorily for its intended purpose. One method of reducing the need for highly skilled workmen is to employ standard parts and procedures wherever possible.

The following sections describe some of the standard parts used extensively in tool design and the advantages in various methods of designing the components of jigs and fixtures. Since there are many complete texts available on the subject of tool design, no attempt is made to cover this subject completely; however, in the ensuing paragraphs, the basic principles involved have been presented for the draftsman's benefit.

17-20. Jig bushings. Drills, reamers, and other cutting tools are guided to their proper position by means of jig bushings. They are hardened in order to provide a wear-resisting surface and are ground inside and outside to obtain the necessary accuracy.

Tables in the "American Machinists' Handbook" or other good handbooks give the dimensions of the three kinds of bushings which have been standardized by the ASA. Press-fit wearing bushings are selected for permanent installation in a jig plate and are used for short-run production only. The renewable bushings are for use in long-run production and are replaced when required. These bushings are installed in the liner bushings.

Bushings are made for standard jig-plate thicknesses of $\frac{5}{16}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{3}{8}$, and $1\frac{3}{4}$ in. They are used as shown in Fig. 17-18.

17-21. Miscellaneous standard parts. Cap screws with fillister heads, socket heads, flat heads, or hexagon heads are commonly used in the con-

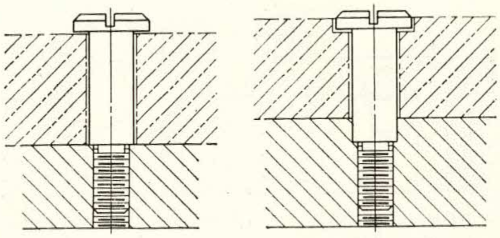
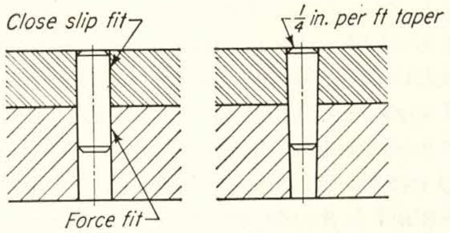

(a) FLUSH SHOULDER (b) RECESSED SHOULDER

Fig. 17-19. Shoulder screws.



(a) STRAIGHT (b) TAPERED

Fig. 17-20. Dowel pins.

struction of jigs and fixtures. When setscrews are used, they should preferably be of the socket type. Shoulder screws are used to retain movable parts (Fig. 17-19). Greater strength is obtained if the shoulder is placed in the recess, as in (*b*). Hexagon nuts used on jigs and fixtures should be of the same size, if possible, in order to avoid the necessity of using more than one wrench.

Figure 17-20 shows the use of a straight and a tapered dowel pin. The straight dowel pin is used extensively. The pin should be a force fit into the body of the fixture and should extend a distance of at least 1½ times the diameter of the pin. The pin should have a close slip fit into the mating part.

Jig feet are used to provide clearance for chips that fall on the machine table and to permit the fastening of screws and other parts to the underneath portions of the jig. Figure 17-21 illustrates the cylindrical type of foot and one which is simply a short socket-head cap screw. A hole is provided in the screw head for tightening with a pin wrench.

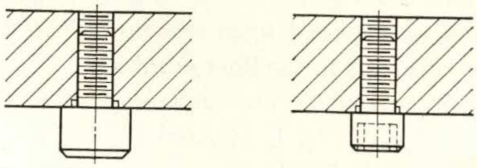

(a) CYLINDRICAL FOOT (b) SOCKET-HEAD CAP SCREW USED AS FOOT

Fig. 17-21. Jig feet.

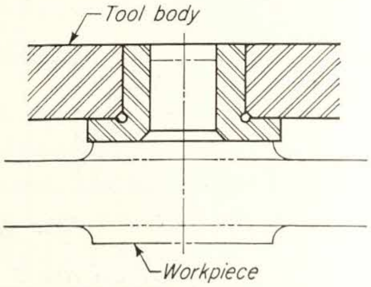


Fig. 17-22. Flanged-sleeve locator.

In addition to the parts described here and those listed in the Appendix, there are many other pieces, such as locking pins, knobs, and studs, which are commonly used in tool fixtures.

17-22. Locating devices. One of the first decisions to be made in designing a jig or a fixture is that of selecting the method or manner of locating and holding the workpieces within the device. The following principles may be used as guides in selecting and designing a locating means: (1) The locating means should be designed to prevent incorrect loading of the workpiece. (2) The locating points should be placed as far apart as possible. (3) Careful consideration must be given to the possibility of the occurrence of undesired irregularities in the part if it is a casting or forging. (4) Locating surfaces must be small in order to keep them clean easily. (5) Sharp corners, especially between locators, should be avoided. (6) Locating points should be visible and accessible to the operator.

17-23. Internal location. If the work has projecting lugs or cylindrical parts it can be located in pockets, recesses, or holes put into the body of the jig or fixture. If this method is used, the recess should be chamfered so that the part will enter easily. The recess should be deeper than the work to provide clearance. A small hole in the tool body will prevent air suction and make it easier to remove the workpiece.

Since a ring can be machined more easily than a recess, a locating ring has definite advantages. Two dowel pins are used to position a ring, and three cap screws should be used to hold it in place.

Figure 17-22 shows a flanged sleeve used to locate a workpiece containing a small cylindrical lug. In addition to the sleeve's providing hardened locating surfaces, its further usefulness is apparent when employed in thin sections or plate material. When a part has an irregular contour, it can often be located in a nest built into the tool body.

17-24. External location. Often the workpiece contains machined holes which can be used to locate it in the jig or fixture. In a case of this sort, an external locating device may be used. If the holes are not too large, a simple hardened stud may be used. When a stud is used, it may be of a type that has internal threads, thus permitting a bolt and washer to be used in clamping the workpiece in position.

If the hole in the workpiece is large, then some type of disk locator should be employed. Figure 17-23 shows a type in which a single dowel pin is placed at the center to position the disk. At least three cap screws should be used to secure the disk to the tool body. When very large holes exist, a ring locator can also be used for positioning the part.

If the workpiece contains holes that have already been machined, these can be used as location points for other machining operations. In this instance, flatted locating pins should be used. It should be noted here that a single pin may be used in conjunction with any one of the location methods already described.

17-25. Stops. A fixed or adjustable stop is used when the work cannot be located either over a plug or in a recess. Figure 17-24 shows several types of fixed stop-locating devices. Notice that a clearance is always maintained for chips and burrs.

Castings or forgings are likely to have irregularities or otherwise vary in size. In this case, the first machining can often be done by sight. This provides the initial locating surfaces. When this cannot be done, an adjustable stop must often be provided in the tool body. The stops should always be located so that they are readily and easily accessible.

17-26. Centralizers. A centralizer is, in general, a V-shaped fixed or adjustable stop. It is employed for work on cylindrically shaped pieces. The work is centered by locating it in the notch of the centralizer 90° V slot. See Fig. 17-25.

17-27. Work supports. After the workpiece has been located, it must be supported in a manner that will avoid distortion by either the clamping force or the force of the cut. Frequently the body of the tool can be used for this purpose by providing clearance space for chips and dirt. Where conditions permit, hardened dowel pins may be bottomed in their holes and used as fixed supports.

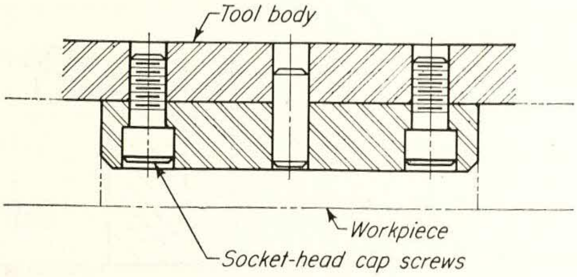


Fig. 17-23. Disk locator.

A fixed adjustable support is often used in connection with one or more fixed supports when variations in the work are likely to be encountered. There are several varieties of fixed adjustable supports, which actually amount to a form of jack. Many versatile versions of these may be found in the "Tool Engineers' Handbook."

17-28. Clamping devices. Clamping devices must be of a type that can be rapidly applied, be easy to operate, and be designed so that they can be operated only in the correct manner. They usually clamp the side of the workpiece or its top, de-

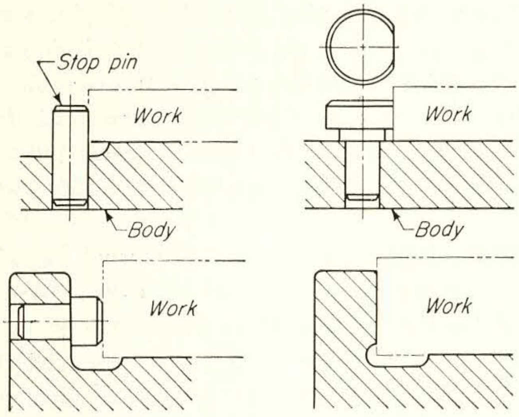


Fig. 17-24. Fixed stops.

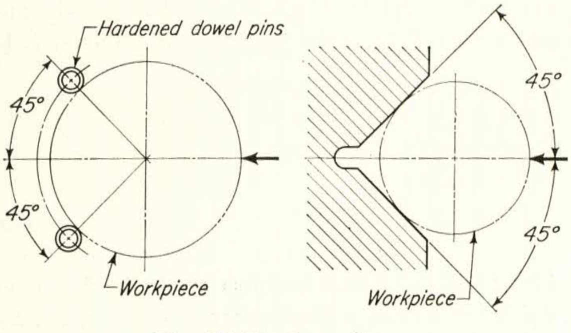


Fig. 17-25. Centralizers.

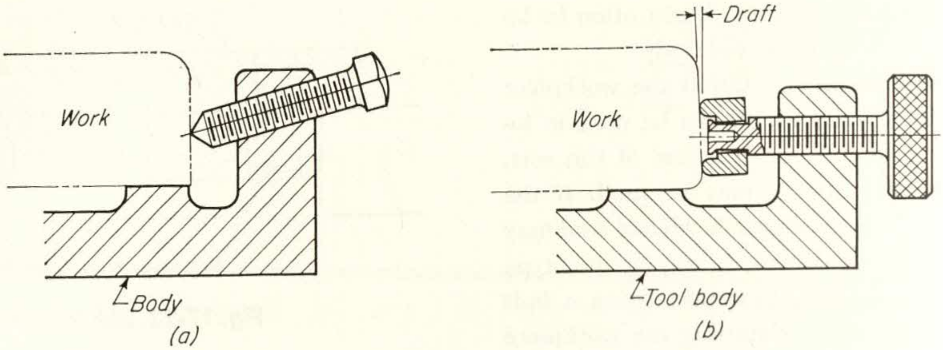


Fig. 17-26. Side clamps.

pending upon the side or surface on which the cutting operation is to be performed.

One of the simplest types of side clamps is the ordinary cone-point setscrew (Fig. 17-26). Since this kind of point on a screw may damage the work, a more suitable point is shown on the screw in (*b*). The other end may be knurled as indicated or formed in the shape of a thumbscrew.

There are also several varieties of toe clamps which can be operated from the side of the work. When toe clamps are used, it should be kept in mind that, in all cases, a small component of the clamping force is exerted downward.

Various top-clamping methods employing screws or nuts with studs may also be used. It is desirable to use springs when resorting to top clamping in order to permit easier insertion and removal of the work. Other methods that employ levers and cams for quick and positive operation are used extensively.

17-29. Jig leaves. A jig leaf is usually a swinging or hinged cover which can be lowered over the workpiece. If drill bushings are contained in the leaf, then a positive stop should be provided. The leaf should be designed so that, when opened, it will not fall back and strike the machine table.

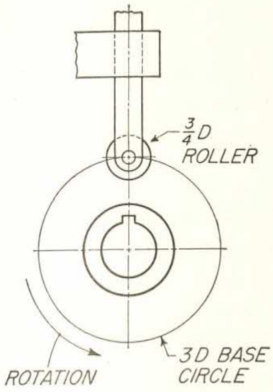
17-30. Ejection. The draftsman must assure himself that the workpieces can be quickly and easily removed from the jig or fixture. This may be as simple as providing large clearances so that the piece can be removed by hand. In some instances, because of unavoidable design limitations, it may require special ejection pins below the workpiece or even elaborate ejection means such as pneumatic power.

17-31. Jig and fixture bodies. The body of the jig or fixture is the part which holds the various accessories and devices in the proper relationship to each other. Considerable ingenuity is often required of the tool designer in selecting a body design which is the most economical to produce. In the case of tools which are to be used only once or for short-production runs, the designer may find almost anything close at hand which can be quickly adapted as a tool body. At other times, it may be desirable or even necessary to design a very elaborate body.

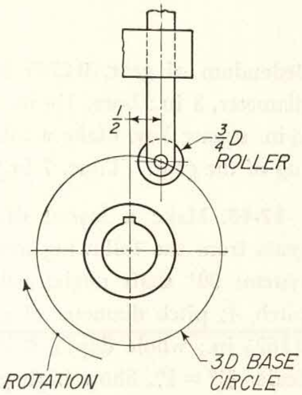
The two methods most used in constructing tool bodies are welding and fabrication. Standard steel shapes may often be found or selected which will make it possible to weld up a satisfactory body. Fabrication means that the individual parts of the jig are secured together with screws or bolts or other separable means. If many similar tools are to be built or if the shape is a complicated one, then a casting of a carefully designed tool body may be the best solution to the problem.

PROBLEMS

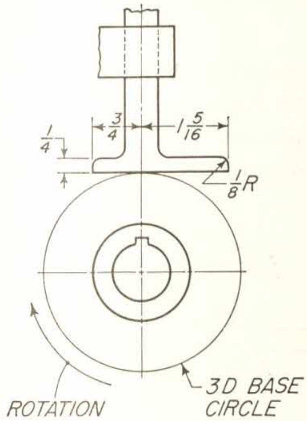
17-1 to 17-7. In each problem shown in the accompanying table, draw a displacement diagram and a cam profile (showing the working curve). In each case, the cam dimensions are as follows: base circle, 3 in. diameter; hub, 1½ in. diameter and ⅞-in.-diameter hole; and key, $\frac{3}{16}$ in. square. The remaining requirements are shown in the table and the figure.



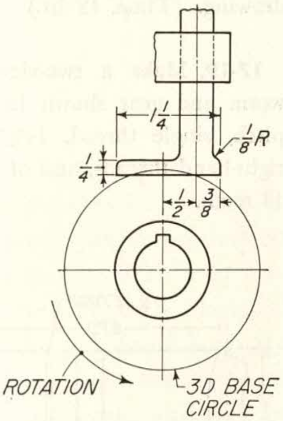
Prob. 17-1. Reciprocating roller follower.



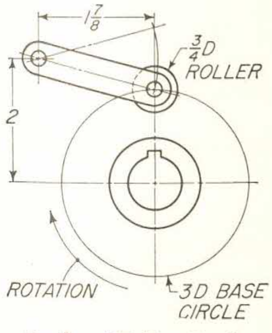
Prob. 17-2. Offset reciprocating roller follower.



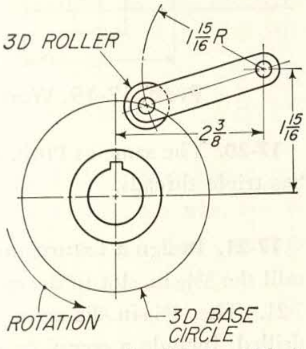
Prob. 17-3. Flat-face follower.



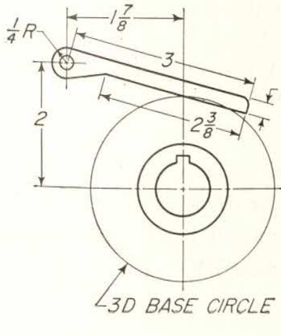
Prob. 17-4. Offset flat-face follower.



Prob. 17-5. Oscillating roller follower.



Prob. 17-6. Offset oscillating roller follower.



Prob. 17-7. Flat-face oscillating follower.

Problem	Cam rotation	Follower motion			Rise
		Rise	Dwell	Return	
17-1	CCW	0°–180° harmonic	180°–210°	210°–360° uniform	1 in.
17-2	C	0°–150° uniform	None	150°–360° harmonic	1 in.
17-3	C	0°–270° parabolic	None	270°–360° parabolic	1 in.
17-4	CCW	0°–180° modified uniform	180°–240°	240°–360° modified uniform	1 in.
17-5	C	0°–120° uniform	120°–240°	240°–360° uniform	30°
17-6	CCW	0°–180° harmonic	None	180°–360° harmonic	30°
17-7	C	0°–180° parabolic	None	180°–360° parabolic	30°

17-8. Draw a displacement diagram and a cam profile (showing the theoretical curve and the working curve) of a cam that turns clockwise with a modified uniform motion through 180°, returning to the starting point with gravity motion, and raising its vertical roller follower, which is ¾ in. in diameter, through a complete rise of 1 in. Make the base circle of the cam 3 in. in diameter, its hub 1½ in. in diameter, the diameter of the hole through it ⅞ in., and include a key slot for a 3/16-in. square key. (Time. 4 hr.)

17-9. Show the working curve for the cam in Prob. 17-1 when acting on a vertical 2-in. flat-faced follower. (Time. 4 hr for complete problem.)

17-10. A cam raising a vertical roller follower goes through the following sequences: It starts with modified uniform motion, the rise being 1 in. through 120°. It continues with harmonic motion, with a rise of 1 in. through 100°. It dwells through 10° and completes the cycle with gravity motion in a total time lapse of 90 sec. Construct a displacement diagram, labeling it according to time intervals, angular cam displacement, motion intervals, and types of motion. Construct the front elevation of a plate cam that will provide these motions, showing the locations of the pressure angles, the theoretical curve, and the working curve for a roller follower ⅞ in. in diameter. Make the diameter of the base circle 1¾ in., the diameter of the hub 1½ in., and the diameter of the shaft ¾ in. Show a ¼-in. square key in the assembly. Place dimensions on the cam drawing. (Time. 5 hr.)

17-11. Construct a plate cam with a flat-faced follower to accomplish the desired motions of Prob. 17-10, showing correction for interference. (Time. 5 hr for complete problem.)

17-12. The following information is available for making a front- and side-view drawing of a spur gear: *3DP, 8PD,* 24 teeth, ⅞-in. face, to fit 1-in. shaft, and fixed in place with a ¼-in. square key. Make a suitable working drawing with the addition of the proper computed dimensions. Scale your drawings to fit the size sheet used. (Time. 4 hr.)

17-13. A pinion has 12 teeth; its outside diameter measures 7 in., its face is 1 in., and the hub is 2 in. in diameter. The shaft is 1¼ in. in diameter. Included is a flat key ¼ by ⅜ by 1 in. Make a working drawing showing all required dimensions. (Time. 4 hr.)

17-14. Make an assembly drawing of a spur gear and pinion with specifications as follows: The gear (*A*) has 21 teeth, *3DP, 7PD,* hub 4 in. in diameter, hole 2 in. in diameter, and face 1½ in. The mating pinion (*B*) has 15 teeth, *5PD,* and a hole 1¾ in. in diameter. Show suitable keys in keyways. Gear is cast-iron alloy. Pinion is made of steel. (Time. 7 hr.)

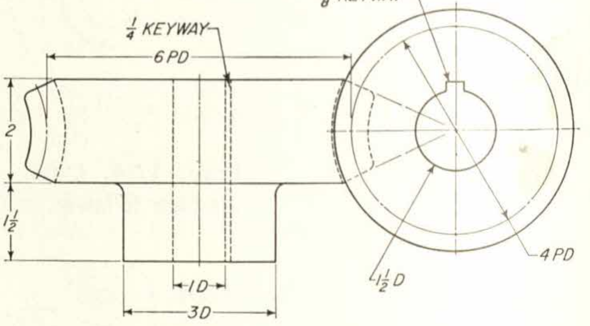
17-15. Draw the mating rack for the gear in Prob. 17-12. The rack is 9 in. long, 2 in. high, and 1½ in. thick. Use suitable scale. (Time. 2 hr.)

17-16. An assembly of a bevel gear with its mating pinion set on intersecting shaft centers reveals the following information: 20° full-depth system; shaft angle, 90°; diametral pitch, 3; teeth in gear, 30; teeth in pinion, 15; pitch diameter of gear, 10 in.; pitch diameter of pinion, 5 in.; addendum of gear, 0.2167 in.; addendum of pinion, 0.4500 in.; whole depth, 0.7293 in.; face width of gear and pinion, 2 in.; hub diameters, gear 5 in., pinion 3¾ in.; hole in gear hub, 2 in. in diameter by 3⅞ in. long. Make an assembly drawing of the gears. Supply all other calculations for proper dimensioning. Scale of drawing: ½″ = 1″. (Time. 10 hr.)

17-17. On inspection, the bevel gear of a bevel-gear and pinion assembly reveals the following data: 20° full-depth system; 90° shaft angle; diametral pitch, 8; teeth in gear, 40; pitch diameter of gear, 5 in.; pitch diameter of pinion, 2½ in.; addendum of gear, 0.0812 in.; dedendum of gear, 0.2735 in.; ⅞ in. face width; hub diameter, 3 in.; bore, 1½ in. diameter by $1\frac{27}{32}$ in. long; ¼-in. square key. Make a full-scale sectional view drawing of the gear. (Time. 7 hr.)

17-18. Make a layout drawing of a pair of bevel gears from the following available data: 20° full-depth system; 90° shaft angle; velocity ratio, 2:1; diametral pitch, 4; pitch diameter of gear, 8 in.; gear addendum, 0.1625 in.; whole depth, 0.5470 in.; 1½ in. face width. Scale: ¾″ = 1″. Show both gear and pinion in section and two teeth of each from their developed back cones. Refer to illustrations in Chap. 17 to calculate other required dimensions. Assume suitable proportions for webs, hubs, bores, slots, etc. Dimension as a working drawing. (Time. 12 hr.)

17-19. Make a two-view assembly drawing of the worm and gear shown in the figure. The worm is 3 pitch, single thread, 14½° pressure angle, 4-in. face, right-hand threads, and of hardened steel. The gear has 18 teeth.



Prob. 17-19. Worm and worm gear.

17-20. The same as Prob. 17-19, except that the worm has triple threads.

17-21. Design a fixture and make a layout drawing to mill the $3\frac{5}{16}$-in. slot in the cast-iron tool support of Prob. 7-21. The $\frac{11}{16}$-in.-diameter hole has been previously drilled. Include a complete bill of material.

17-22. Design a drill jig and make a layout drawing to drill the two ⅜-in. holes in the cast-iron bracket of Prob. 8-4. The ⅞-in. central hole has been reamed and the bottom surfaced finished. A bill of material should be included.

17-23. Design a drill jig and make a layout drawing to drill the four ⅝-in. holes in the die shoe of Prob. 8-15. This is the last machining operation in the production of this part. Include a bill of material.

Chapter 18

ELECTRICAL DRAWING*

The recent tremendous advances in electronics, automatic control, and electric power production have brought many engineers and draftsmen into occasional, if not daily, contact with electrical drawings. This aspect of the graphical language can no longer be confined solely to the electrical field; and the engineer or draftsman, although he may be trained in other areas, may at any time be confronted with the problem of reading, making, or supervising the preparation of an electrical drawing. For this reason, he should be familiar with the types of electrical drawings that are commonly employed and the procedures used in preparing them.

In addition to the standard orthographic projection used to describe parts which make up certain electrical machines, there are four general types of electrical drawings:

1. Pictorial drawings
2. Wiring plans or diagrams
3. Block diagrams
4. Schematic diagrams

Although each type is considered separately herein, it is not uncommon to find combinations of two or more of these types in one drawing.

18-1. Pictorial drawings. It is often desirable to show a component, series of components, or a machine by means of pictorial representation (see Fig. 18-1). A pictorial outline may also be used to provide a background for a wiring circuit. This may take the form of an isometric, perspective, or oblique drawing (see Fig. 18-2).

In deciding whether or not a pictorial drawing should be used, the engineer or draftsman must consider the use which will be made of the drawing and the technical background of the person who must interpret it. He should select the type of pictorial drawing which will best portray the object, and, of course, the one which is the simplest to draw consistent with the principle of clarity. Chapter 11 covers the steps used in the preparation of pictorial drawings.

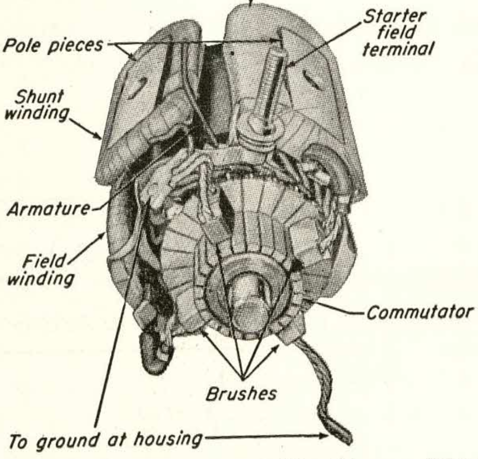


Fig. 18-1. Starting motor assembly. (Mercury Division of Ford Motor Company.)

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* This chapter was written by Prof. Charles J. Baer.

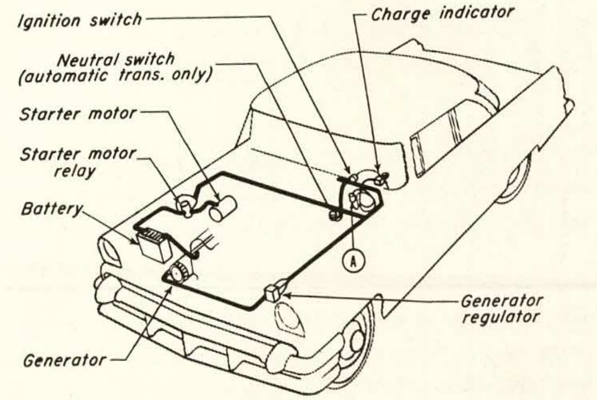


Fig. 18-2. Starting, power, charging, and neutral switch (auto transmission) circuits. (*Mercury Division of Ford Motor Company.*)

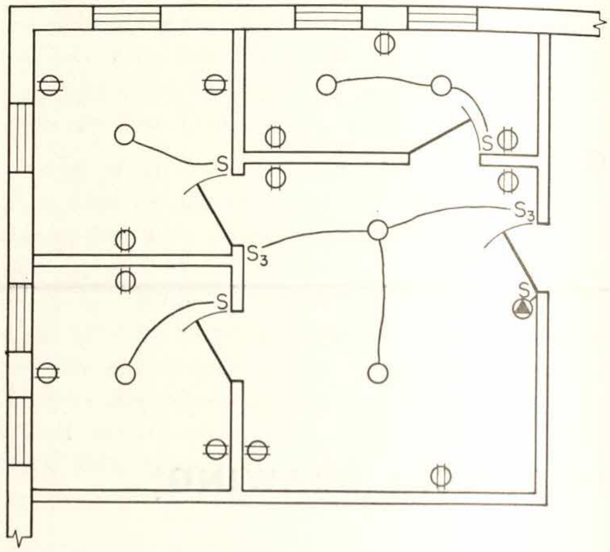


Fig. 18-4. Simple wiring plan for executive office suite.

18-2. Wiring diagrams. The wiring diagram is used widely in the manufacturing and architectural fields, but infrequently by design and research engineers. However, a knowledge of its use would be helpful to most engineers and draftsmen.

The two pictorial drawings (Figs. 18-1 and 18-2) might also be considered to be wiring drawings. Figure 18-1 was not made expressly for that purpose; however, Fig. 18-2, showing the various automobile wiring circuits, is essentially a wiring diagram. These circuits may also be shown in plan, either singly as in Fig. 18-3, or as several circuits combined into one plan. Note that in both Figs. 18-2 and 18-3 the lines representing wires are drawn as heavy as, or heavier than, the weight recommended for visible object lines in Fig. 20-3. Because of the diversity of circuits used in modern machines, color codes are often used; hence the R-BL (red with blue band) and Y (yellow) code letters shown in Fig. 18-3. In actual construction, many of the wires are bunched together to form a loose cable, called a "harness."

Another kind of wiring diagram widely used is that which is drawn to represent a wiring circuit, or circuits, in a building. An example, showing the wiring plan for a suite of offices, appears in Fig. 18-4. This conforms to the principles outlined by the Industry of Wiring Design, utilizing symbols specified in the American Standards Association in its Y32.9—1943 standard, entitled Graphical Electrical Symbols for Architectural Plans. The curved lines joining switches to ceiling and other outlets are drawn only to show the relationship of switches to outlets, and the actual location of wires is left to the electrical contractor. Many architects do not observe the standards in a strict manner; hence, variations in the symbols used in building wiring plans may be found in actual practice.

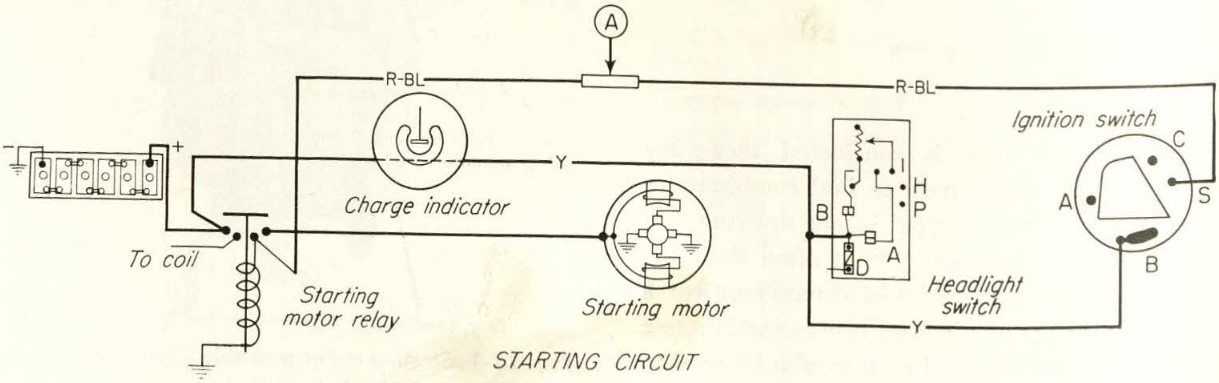


Fig. 18-3. Starting circuit of an automobile.

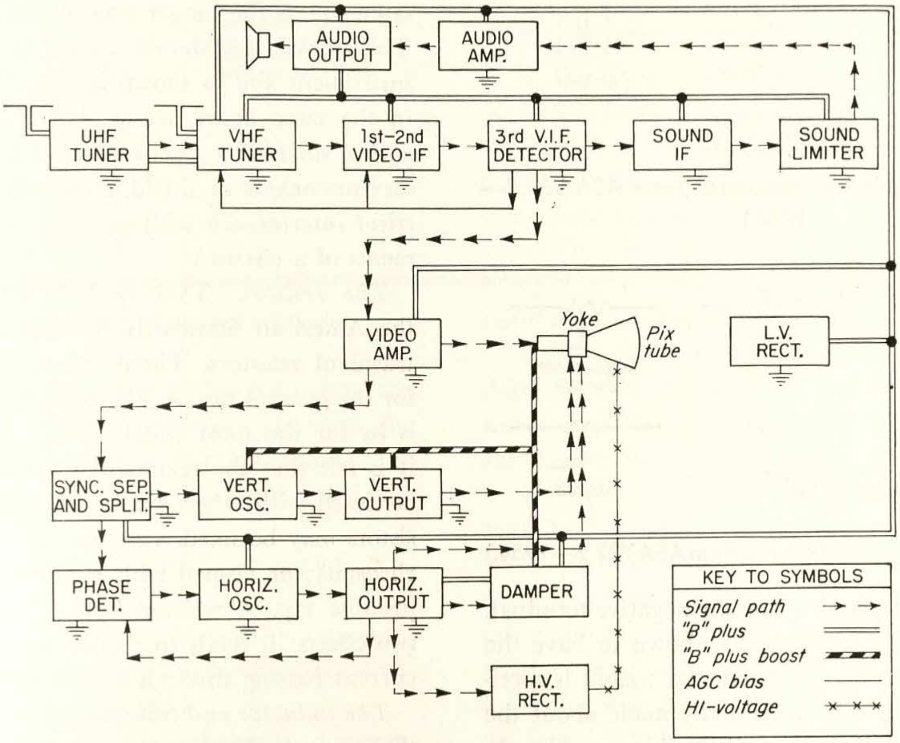
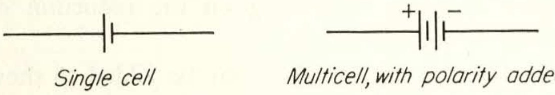


Fig. 18-5. Block diagram of television receiver. (*The Magnavox Co.*)

18-3. Block diagrams. The block diagram, Fig. 18-5, is somewhat similar to a flow diagram (see Fig. 13-18) and shows a clear and simplified representation of the progression of electrical energy through a circuit. It is usually made up of rectangles, with descriptive lettering included within each "block." Each rectangle may represent one element or component within a circuit, or it may represent several different parts (such as tubes, transformers, and capacitors), which together make up a "stage."

Flow is drawn from left to right in relatively simple circuits, but in the more complex ones, using the television receiver for an example, the input is usually placed at the upper left and the output may or may not be at the right side of the diagram. Arrowheads are often used to show the direction of signal flow. A convenient width of line, such as that used for object lines, or slightly thinner, is used, although different-weight lines are sometimes employed in one diagram for purposes of emphasis.

18-4. Symbols for schematic diagrams. A schematic diagram is a functional drawing which traces the path of a signal through an electric circuit and shows the functional relationship of the elements (components or parts) of the circuit to each other and to the circuit as a whole. The elements are shown by symbols which are prescribed in American Standard Y32.2—1954, Graphical Symbols for Electrical Diagrams, and certain other publications.



Single cell *Multicell, with polarity added*

Fig. 18-6. Symbols for batteries. (*From ASA Y32.2—1954.*)

Because the engineer is primarily interested in the functional relationship of electrical components, it is the schematic diagram that is most often seen on engineering drawing boards. A knowledge of how to draw the symbols of some of the more common elements will enable the engineer or draftsman to prepare any schematic diagram if he is supplied with the proper information. These elements are as follows.

The battery. One of the simplest symbols is that specified for a single-cell battery (see Fig. 18-6). The horizontal line represents the path of the signal, or electrical impulse, usually a wire. The longer vertical line, which appears about $\frac{3}{16}$ in. long in the Standards, represents the positive

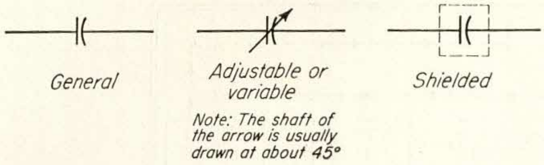


Fig. 18-7. Symbols for capacitors. (From ASA Y32.2—1954.)

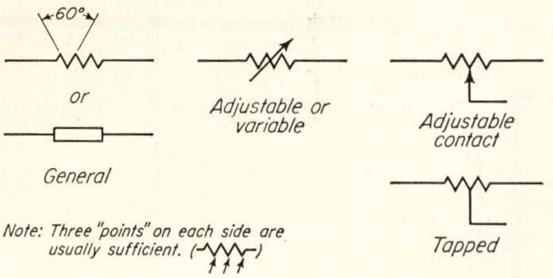


Fig. 18-8. Symbols for resistors. (From ASA Y32.2—1954.)

terminal and the shorter line the negative terminal. In the Standards, all lines are shown to have the same width, although no particular weight is specified. In practice, they are usually made about the weight of object lines, or a little thinner. Also, in the Standards the size of the symbol is recommended as any proportional size that suits a particular drawing, depending on the reduction or enlargement anticipated.

Additional vertical lines may be added to show multicellular batteries as shown on the right side of Fig. 18-6. If desired, plus and minus signs may be placed adjacent to the proper symbol lines.

The capacitor. Another symbol that is easily made is that depicting a capacitor, sometimes called a "condenser," whose main function is to store electrical charge. The straight line is made about the same size as the longer line of the battery symbol. The curved line should always be drawn with an instrument and as shown in Fig. 18-7. Also shown in the same figure are symbols for an adjustable and a shielded capacitor. (It is sometimes necessary to enclose, or shield, a capacitor to avoid electrical interference with or from other nearby elements of a circuit.)

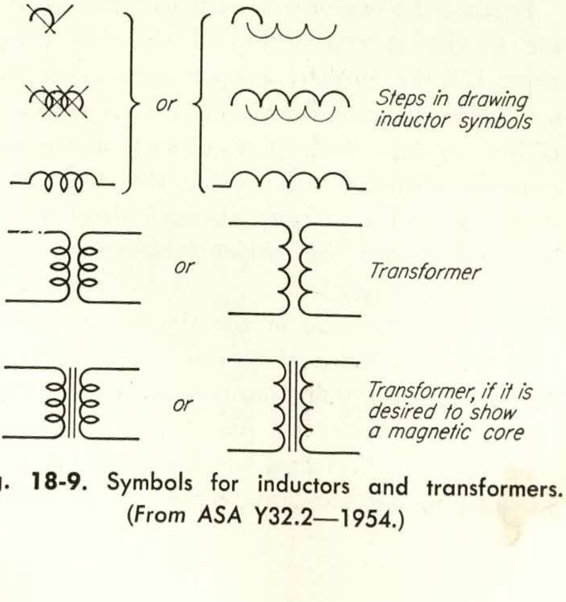

or
Steps in drawing inductor symbols
or
Transformer
or
Transformer, if it is desired to show a magnetic core

Fig. 18-9. Symbols for inductors and transformers. (From ASA Y32.2—1954.)

The resistor. Two symbols are approved by the American Standards Association for the portrayal of resistors. These two symbols are shown for the general case in Fig. 18-8. The zigzag symbol is by far the most widely used, probably because it is felt that the rectangular symbol is too easily confused with others having the same outline. Resistors may be fixed, variable (as in the case of a rheostat), or tapped with either a fixed or an adjustable tap. A resistor inserted in a circuit has two effects: it tends to reduce the magnitude of a current passing through it, and it develops heat.

The inductor and transformer. An inductor has the property that it opposes any change of current that passes through it.

Inductor wirings are shown by either of two approved symbols (see Fig. 18-9). The older symbol, which appropriately pictures a coil, is still widely used. However, the newer symbol, shown at the right, is gaining in popularity because of its ease of execution when special electrical templates are used. The same symbols are used in drawing transformers.

The electron tube and transistor. There are literally hundreds of types of electron tubes produced today. Their functions are many, among which are rectification, amplification, and oscillation. Transistors are much simpler in design yet do many of the same things that tubes can do. Tubes may be classed as diodes (having two electrodes—a plate and a cathode), triodes (having three electrodes—a plate, cathode, and grid), tetrodes (having four electrodes—two grids, plate, and cathode), and pentodes (having five electrodes—three grids, plate, and cathode). Most tubes contain a heating element known as a "filament."

The symbol (at right) and functional operation (at left) of a triode tube are shown in Fig. 18-10.

The symbols for transistors, which are easily made, are shown in the Appendix.

Other symbols. Symbols for other often-used electrical components, as specified in ASA Y32.2,

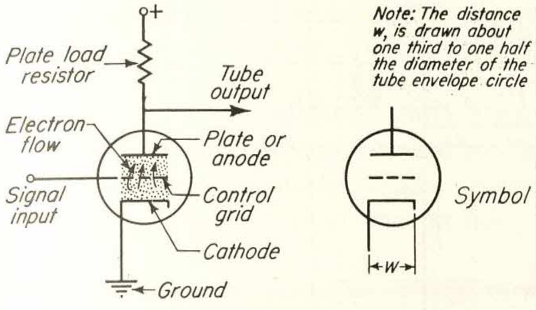


Fig. 18-10. Action of grid-controlled triode.

appear in the Appendix. Space does not permit the inclusion of all electrical symbols, because the Standard is a 56-page booklet. For this reason, every drafting room should have at least one copy in its library.

A number of devices are manufactured for the purpose of helping the draftsman make symbols easily and quickly. These are usually templates which are in stencil form or the guiding type similar to that shown in Fig. 18-11.

18-5. Preparation of the schematic diagram. The following list gives a number of rules which govern the preparation of schematic diagrams:

1. The weight of a line does not alter the meaning of a symbol. When desired, an extra-heavy line may be used for emphasis.

2. A symbol may be drawn to any proportional size that suits a particular drawing, depending on the reduction or enlargement anticipated. Occasionally, for purposes of contrast, some symbols may be drawn relatively larger than other symbols on a diagram. It is recommended that not more than two sizes be used on any one diagram.

3. Usually all tube circles are made the same size, about 1 in. or more in diameter, on original drawings. Transistor envelopes are sometimes drawn smaller, occasionally as small as ½ in. diameter.

4. Details of type, impedance, rating, etc., may be added, when required, adjacent to any symbol. When this is the case, care must be exercised in planning the drawing to provide space for the letters and figures.

5. The angle at which a connecting lead is brought to a graphical symbol has no particular significance unless otherwise noted.

6. The orientation of a symbol on a drawing does not alter the meaning of a symbol. In other words, a symbol may be rotated 90° or 180° from the position in which it appears in the Standard.

7. Lines are usually drawn vertically or horizontally but may be drawn in other directions when circumstances so dictate.

8. The signal path is from left to right. In other words, the energy source, such as the input channel or antenna, is at the left; and the output, a loudspeaker, for example, is at the right. In large drawings, input is at the upper left, and output is at the lower right.

9. Uniform density is desired, so that symbols are uniformly spaced throughout the drawing and no congested areas appear.

10. Lettering (including figures) must be perfect. Poor lettering on an electrical drawing cannot be condoned in either an engineering design office or in the drafting rooms of an electrical manufacturer.

In many cases, the finished drawing will be made from a rough sketch, probably coming from the designing engineer. It will show the elements in their proper relationship with one another, and the signal flow will be from left to right (see Fig.

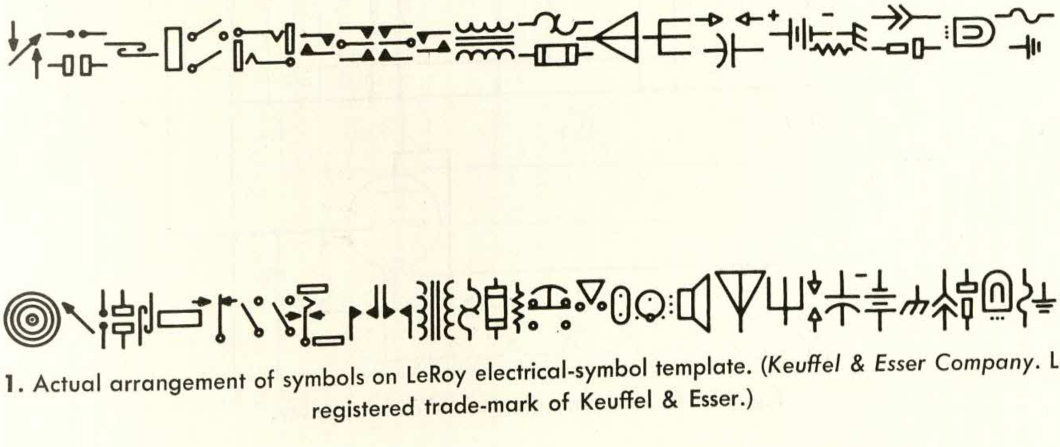


Fig. 18-11. Actual arrangement of symbols on LeRoy electrical-symbol template. (*Keuffel & Esser Company.* LeRoy is a registered trade-mark of Keuffel & Esser.)

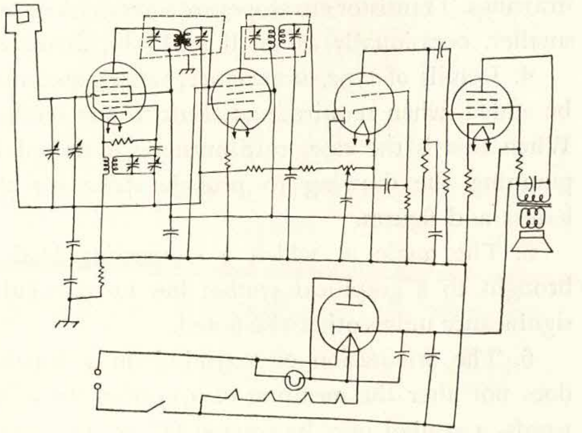


Fig. 18-12. Rough engineering sketch of a-c–d-c superheterodyne receiver.

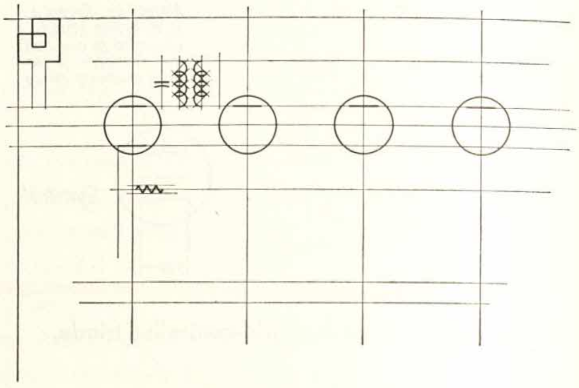


Fig. 18-13. Initial steps in laying out the schematic diagram.

18-12). However, many of the principles just listed will probably be neglected in the sketch. Therefore, it will be the duty of the detailer or draftsman to see that they are observed in the making of the finished schematic diagram.

After studying the sketch, the draftsman should lay out the center lines of the tubes in the main part of the circuit, placing them on a horizontal center line, and taking care to see that sufficient room is allotted between tubes for the transformers and capacitors that are enclosed within the dotted lines (called "interstage coupling transformers") in the example of Fig. 18-12. About the same space is left between the third and fourth tubes to allow room for the resistors just below, and also because a more professional appearance will result if the four tubes are spaced evenly (see Fig. 18-13).

Several horizontal construction lines drawn below the tube center line will facilitate the location of connecting leads to other parts, including the auxiliary circuits. The diode rectifier, power supply, and heater should be placed below, which is the proper location for auxiliary circuits. If these concepts and principles are observed, the completed schematic will be neat and easy to read and

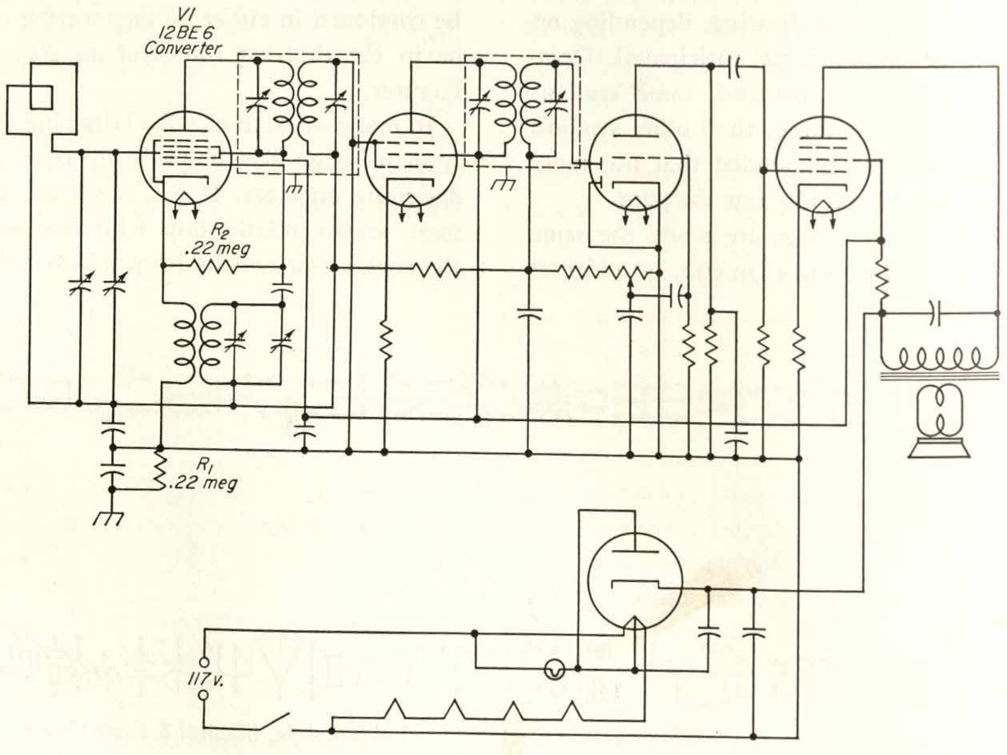
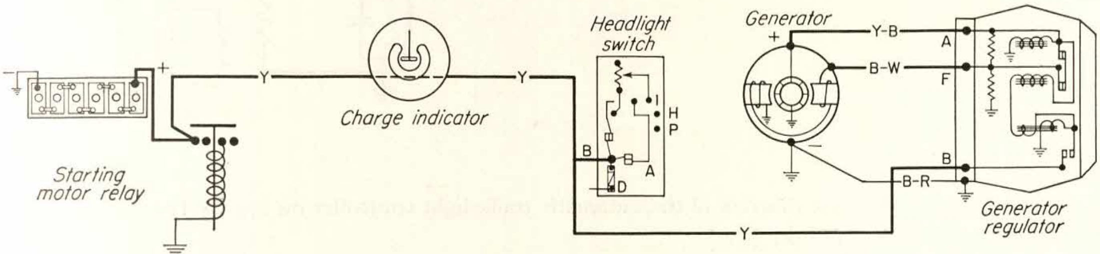


Fig. 18-14. Schematic diagram of radio receiver.

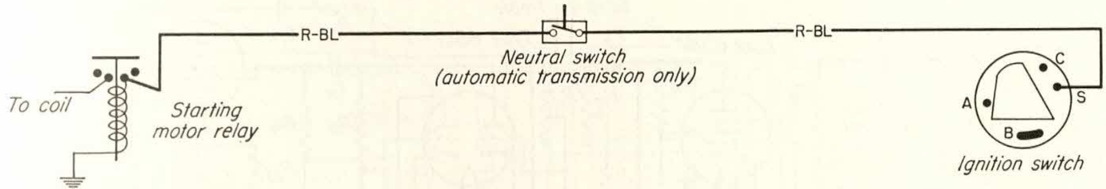
the signal path can be traced from the input to its terminus. The finished circuit would appear in a form similar to Fig. 18-14.

In many cases, it is desirable to identify elements of a circuit by placing certain information above or adjacent to the symbol. ASA Y14.15, Schematic Diagrams, which is in the draft stage at this writing, states that electron tubes shall be identified by a reference designation and tube-type number and that the circuit function of the tube may also be included. One tube and two resistors in Fig. 18-14 have been referenced, using the approved standardized system.

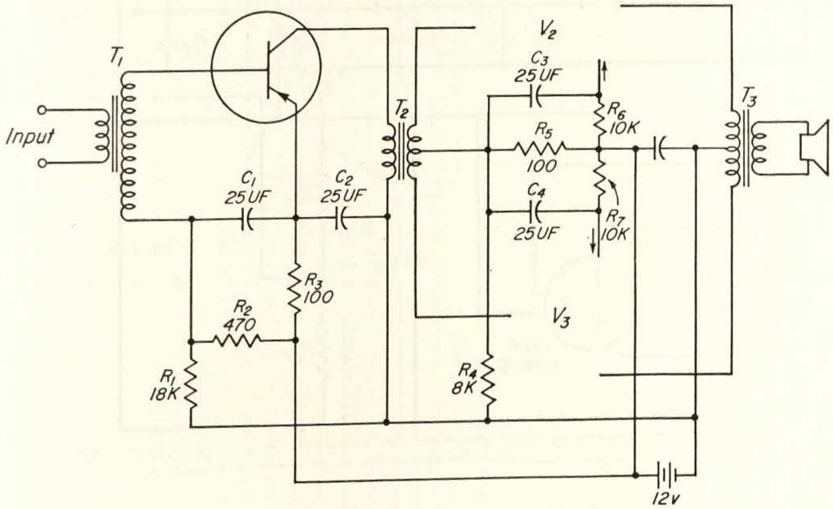
PROBLEMS



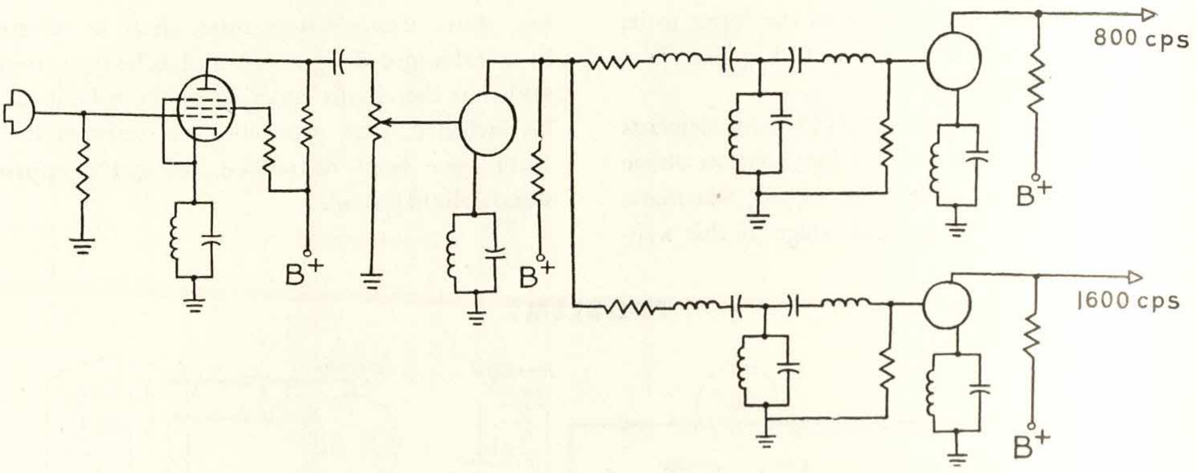
POWER AND CHARGING CIRCUIT



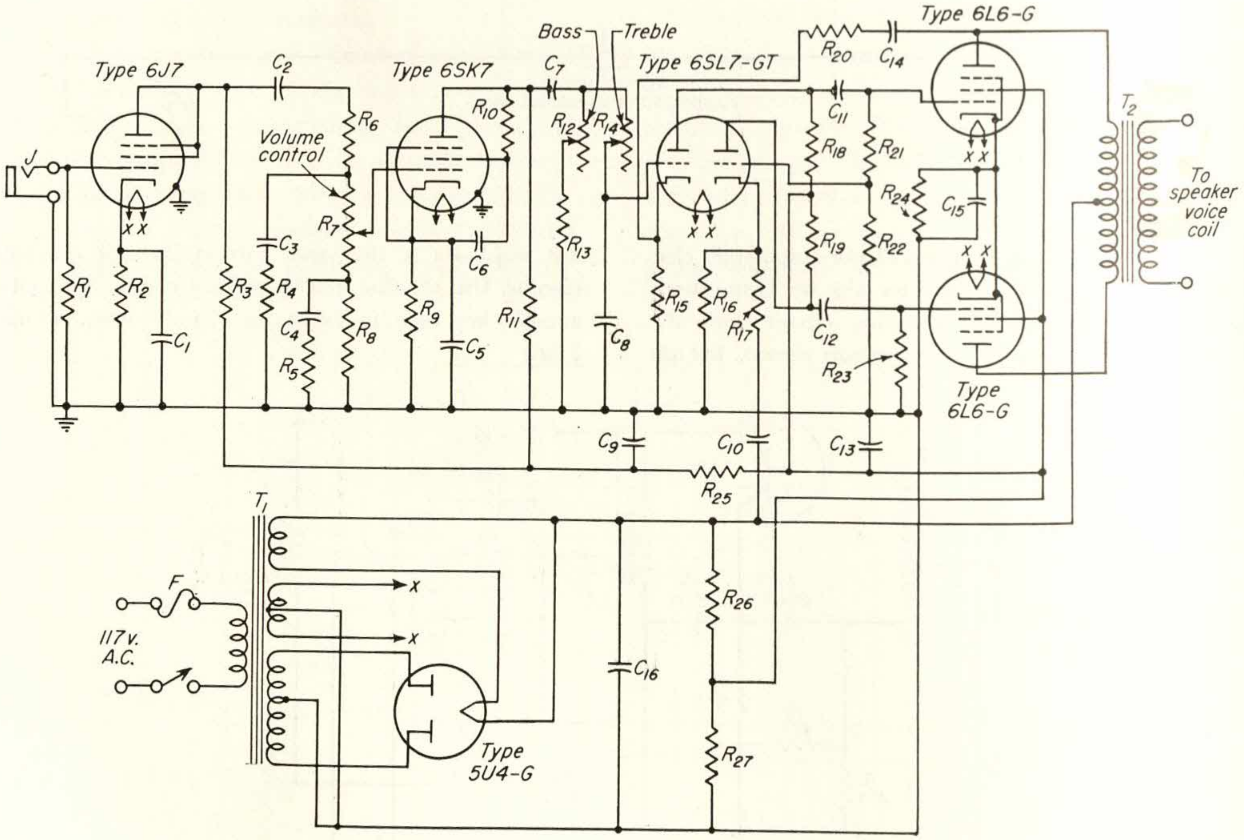
18-1. Make a wiring diagram of the automobile electrical circuits in a plan view on 8½- by 11-in. sheet. Combine the power and charging circuit with the neutral-switch circuit. Use the symbols shown, but do not duplicate if the same part is included in both circuits. Use the line weights as they appear here. Give a color key code in lower right-hand corner. (Time. 3 hr.)



18-2. Make a schematic diagram of the audio-amplifier circuit on 8½- by 11-in. paper. In the spaces marked V_2 and V_3, construct *p-n-p* junction transistor symbols identical to the transistor symbol appearing at the upper left. The small arrows show the direction of current flow. Label all components as shown. Label transistors as follows: *p-n-p* triode, type 2N34. (Time. 3 hr.)

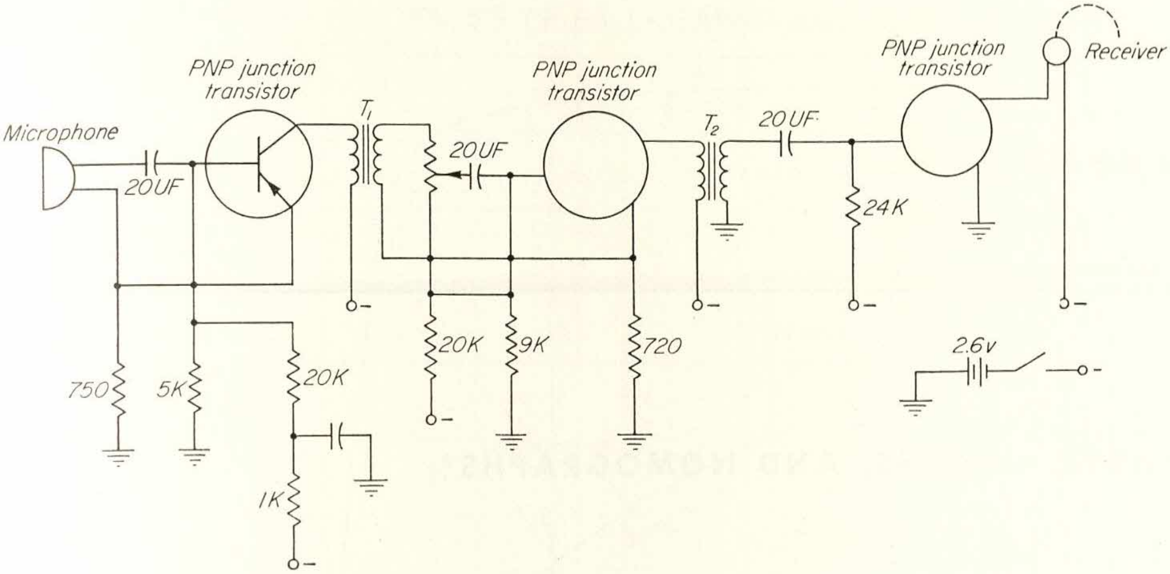


18-3. Make a finished schematic diagram of the automatic traffic-light controller on 8½- by 11-in. paper. The three incomplete tubes are triodes. (Time. 3 hr.)

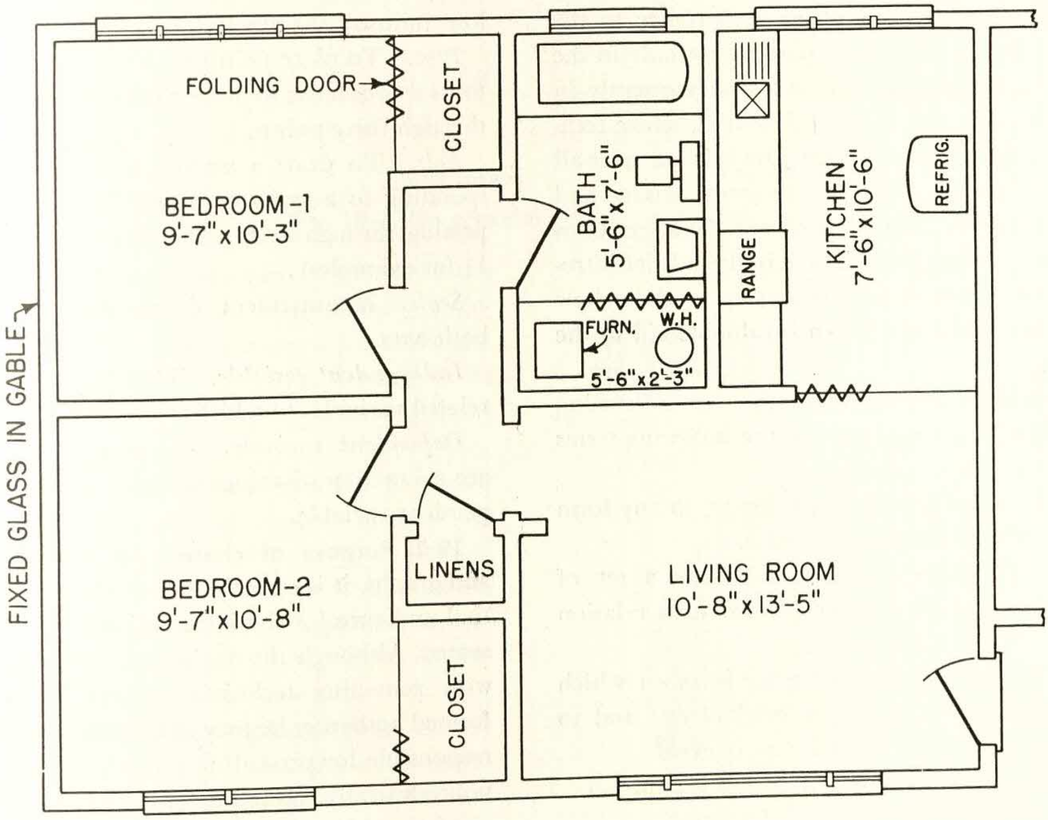


18-4. Make a neat freehand sketch of the high-power audio amplifier on 8½- by 11-in. paper. Label all parts as shown. Use a single weight of line throughout. Use the newer coil symbol in the transformers. (Time. 3 hr.)

18-5. Make a schematic drawing of the high-power audio amplifier, using instruments, on 11- by 17-in. sheet. Use the newer coil symbols. (Time. 6 hr.)



18-6. Draw a schematic diagram of the all-transistor hearing aid on 8½- by 11-in. sheet. Complete the second and third transistor symbols, and label all elements as they appear on the drawing. (Time. 2 hr.)



18-7. Make a floor plan of one unit of the duplex apartment on 8½- by 11-in. sheet, using a scale of ¼" = 1'-0". Then put a wiring diagram on this floor plan, showing all necessary outlets and lighting fixtures. It is suggested that bedrooms have four convenience outlets each and that, instead of overhead lights in the living room, one or more convenience outlets be connected to switch (es) near entry point (s). (Time. 3 hr.)

Chapter 19

CHARTS, GRAPHS, AND NOMOGRAPHS*

The ability to present data in graphical form and to solve and analyze engineering problems by graphical methods is of prime importance to the engineer. He finds charts important not only in the technical aspects of his job but also frequently in business reports and in talks delivered before technical societies. This chapter provides an over-all survey of various types of common charts and graphs and gives a number of specific suggestions on how to prepare them. There is also a brief introduction to elementary nomography to show how this graphical tool can be an invaluable aid to the engineer.

19-1. Basic chart terminology. In discussing and drawing charts and graphs, the following terms will be used (see also Fig. 19-1):

Chart. An inclusive term referring to any form of graphical representation of data.

Graph. A type of chart; ordinarily a set of points connected by a curve plotted with relation to two or more variables.

Axis. One of the two or more lines on which fixed values of the variables are laid out and to which the elements of a graph are referred.

Abscissa. The horizontal axis of a graph.

Ordinate. The vertical axis of a graph.

Origin. The intersection of the horizontal and vertical axes.

Coordinates. The x coordinate of a point is its horizontal distance to the right (plus) or to the left (minus) of the ordinate, or y axis; the y coordinate of a point is its vertical distance above (plus) or below (minus) the abscissa, or x axis.

Plot. To place points on a graph with reference to its coordinates; to make a curve by drawing a line through these points.

Fair. To draw a smooth curve roughly corresponding to a series of points but not necessarily passing through each point (see Figs. 19-8 and 19-11 for examples).

Scale. Measurement divisions along either or both axes.

Independent variable. That one of two or more related variables to which values are assigned.

Dependent variable. A variable whose values are a function of values assigned to a related independent variable.

19-2. Purpose of charts. In preparing charts and graphs, it is essential to keep in mind the eventual audience for the information that is to be presented. Although the engineer is usually concerned with providing technical information to an informed audience, he may also from time to time be responsible for presenting statistical information to nontechnically trained members of his company or to the public. Thus the engineer or draftsman should be familiar with the purposes and construction of the principal types of charts and graphs. These are described in the following paragraphs, starting with the simplest, or one-scale, charts.

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* This chapter was prepared by Jeffrey Norton and incorporates various suggestions of Prof. John T. Rule.

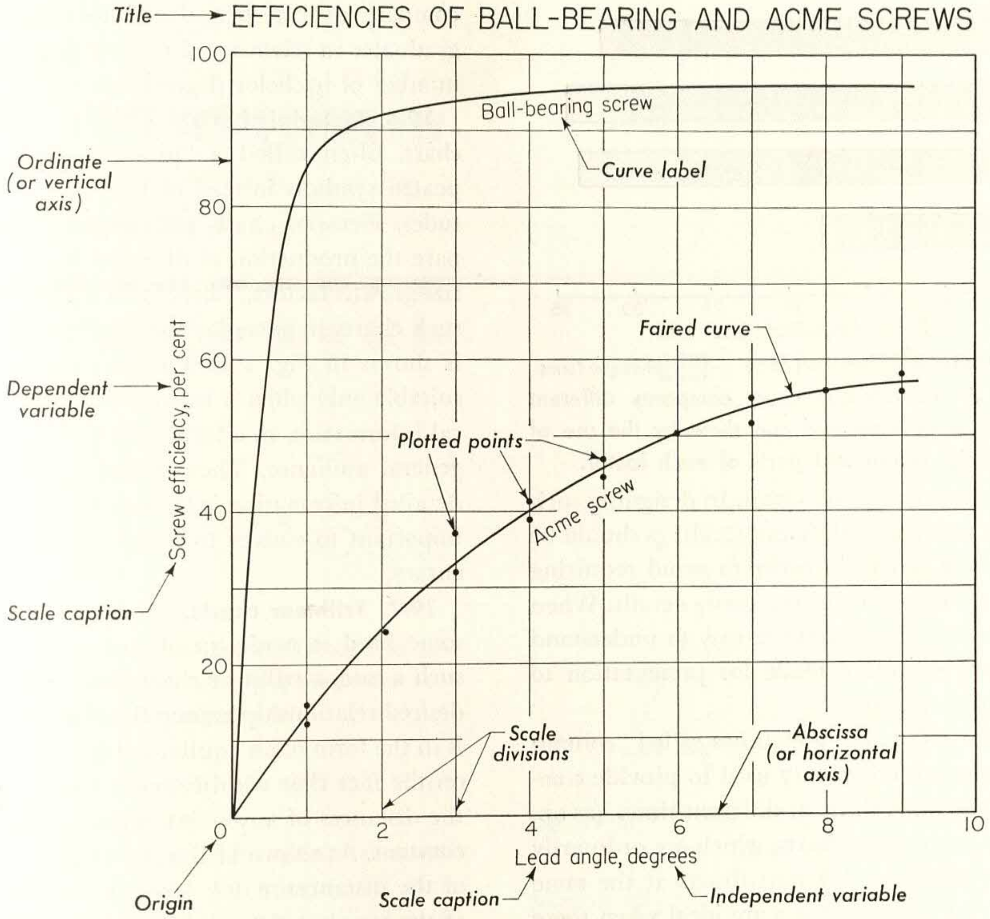


Fig. 19-1. The principal elements of a chart.

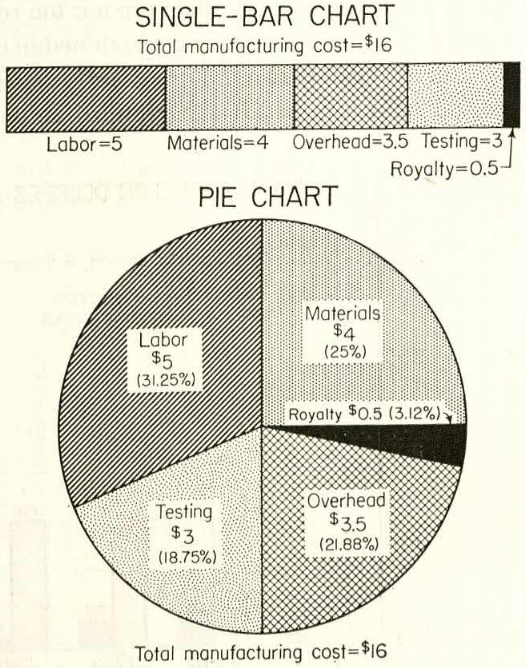


Fig. 19-2. Single-bar charts and pie charts are used to show the constituents of a whole.

19-3. Single-bar and pie charts. Whenever the purpose of a chart is to show how various components add up to make a total, a single-bar chart or a pie chart is useful (see Fig. 19-2). Because of its shape, the pie chart is particularly suited to showing totals of 100 per cent.

19-4. Diagrammatic or flow charts. The most commonly used type of diagrammatic chart is the familiar organization chart that indicates lines of responsibility within a company, association, club, etc. The flow diagram is another type of diagrammatic chart frequently used by engineers. An example is shown in Fig. 13-18.

19-5. Bar charts. A multiple-bar chart is very useful for comparing magnitudes of similar items. In this type of chart, horizontal or vertical bars are used, the lengths of which are proportional to the magnitudes of the quantities represented. By the use of different types of shading, it is possible to show the component parts of each item. Figure 19-3 shows a chart for the 1950 population of the United States over 21 years of age by regions divided into urban,

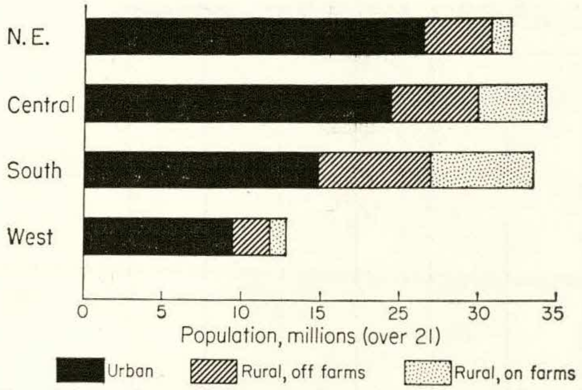


Fig. 19-3. A multiple-bar chart compares different things at the same time and can show by the use of shading the component parts of each factor.

rural not on farms, and on farms. In designing such a chart, the number of different shadings should be limited to four or five in order to avoid requiring the reader to keep track of too many details. When well constructed, bar charts are easy to understand and therefore are often made for presentation to nontechnical audiences.

Vertical-bar charts are sometimes called "column charts." These are commonly used to provide comparisons of the same thing at different times (as opposed to horizontal-bar charts, which are ordinarily best used to compare different things at the same time). Bar and column charts are ideal when there is a limited amount of comparatively simple information to present. When the data are not too complex, two simple bar charts may be combined in one illustration for comparison. Figure 19-4 shows a vertical-bar chart in which the grouped columns compare over a period of years the number of graduates in science and engineering with the total number of bachelor degrees received.

19-6. Pictorial charts. This is a special form of chart, often called a "pictograph," that uses repeated symbols instead of bars to compare magnitudes. Pictorial charts are frequently used to compare the production of different items or to dramatize growth factors. There is an unlimited variety of such charts in everyday use, and one common type is shown in Fig. 19-5. Pictorial charts are usually suitable only when it is necessary to present statistical information in a form that will appeal to a very general audience. They should not be used when detailed information is to be presented or when it is important to convey to readers a strict sense of accuracy.

19-7. Trilinear charts. Frequently a mixture of some kind is made up of just three elements. In such a case, a trilinear chart may be used to show a desired relationship among the elements. This chart is in the form of an equilateral triangle and is based on the fact that within such a triangle the sum of the distances of any point from the three sides is a constant. As shown at the top in Fig. 19-6, the sum of the distances, $a + b + c$, is a constant regardless of the location of P. If this common sum is made to be 100, the point P can be chosen to designate the percentages of three constituents.

This can be used, for instance, to designate any color that can be mixed from three primary colors. In the lower portion of Fig. 19-6, the point P desig-

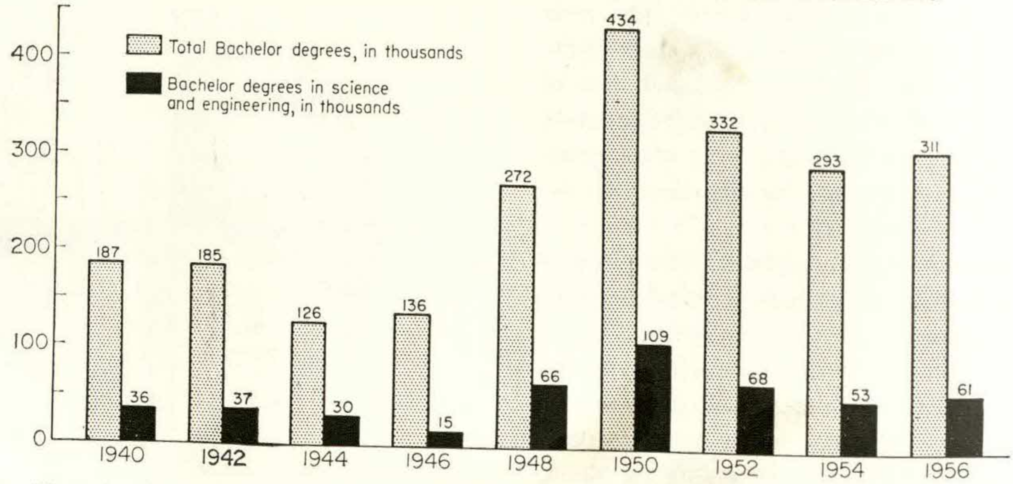


Fig. 19-4. A column chart is best used to compare two related sets of data over a span of time.

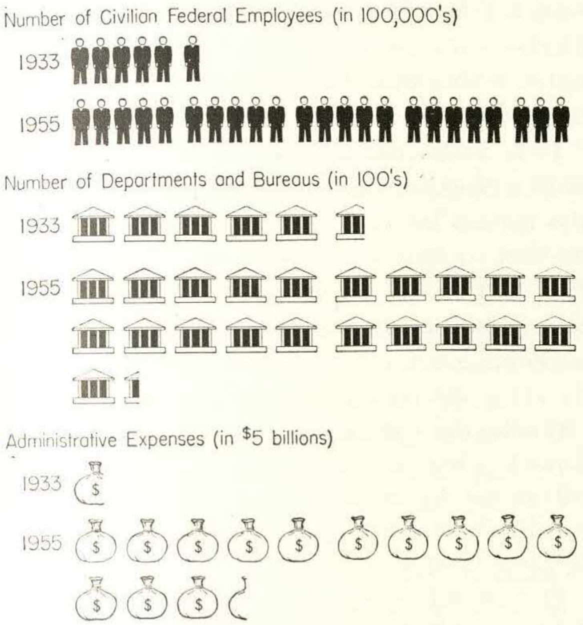


Fig. 19-5. Pictorial charts are generally used to present dramatic comparisons in an appealing form to a general audience.

nates a color composed of 60 per cent red, 30 per cent yellow, and 10 per cent blue.

19-8. Rectilinear charts. The charts discussed thus far compare separate though related facts. Most relationships that are to be shown in a chart, however, are continuous in nature; that is, they are composed of an infinite number of successive points that lie on a curve or line of some sort. Charts of this type are commonly called "graphs" and are usually plotted on a paper divided into small rectangles. When the ruling, or grid, consists of equispaced vertical lines crossing equispaced horizontal lines, the paper (and the graph drawn on it) is called "rectilinear." Rectilinear paper is commercially available with a variety of rulings: For most graph work, paper with ¼-in. ruling each way is convenient; where extreme accuracy is required, paper with a ruling of $\frac{1}{20}$ in., with every fifth line heavier, is more suitable.

Suppose that the temperature of an electrical unit is to be measured. The thermometer is read at arbitrary time intervals, and the results are recorded as in Fig. 19-7. Though only certain readings were taken, it can be assumed that time and temperature are both continuous; that is, at every instant of time there was a temperature. Consequently, a curve that will come very close to representing the true state of affairs can be drawn through the readings taken.

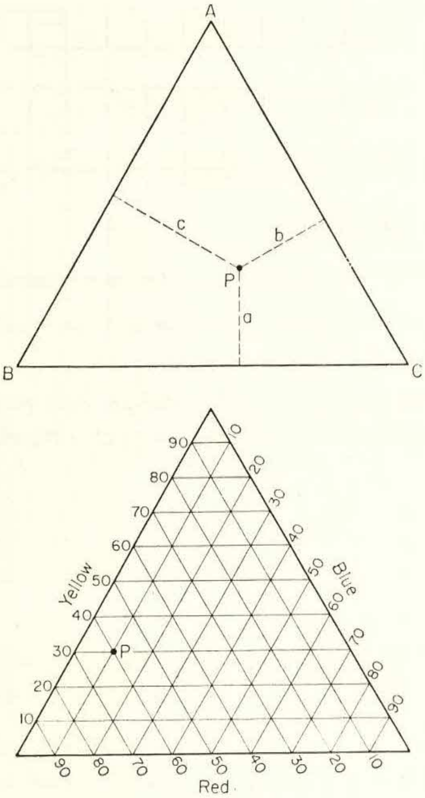


Fig. 19-6. A trilinear chart shows a relationship among three elements.

Theoretically, it should be noted that a curve (or a line) is itself continuous and thus perfectly represents such a relationship. In fact, the modern way of drawing such a graph is to rig up a thermocouple to a recording stylus and to draw a sheet of graph paper under the stylus by clockwork. The result is a continuous graph of temperature with respect to

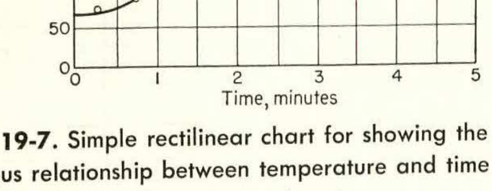


Fig. 19-7. Simple rectilinear chart for showing the continuous relationship between temperature and time during an experiment.

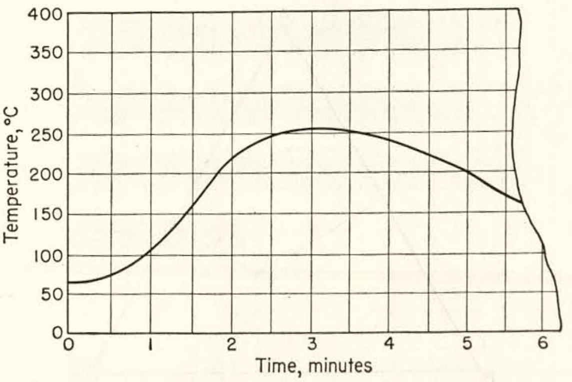


Fig. 19-8. Rectilinear graph of temperature versus time as recorded automatically by means of a thermocouple and stylus.

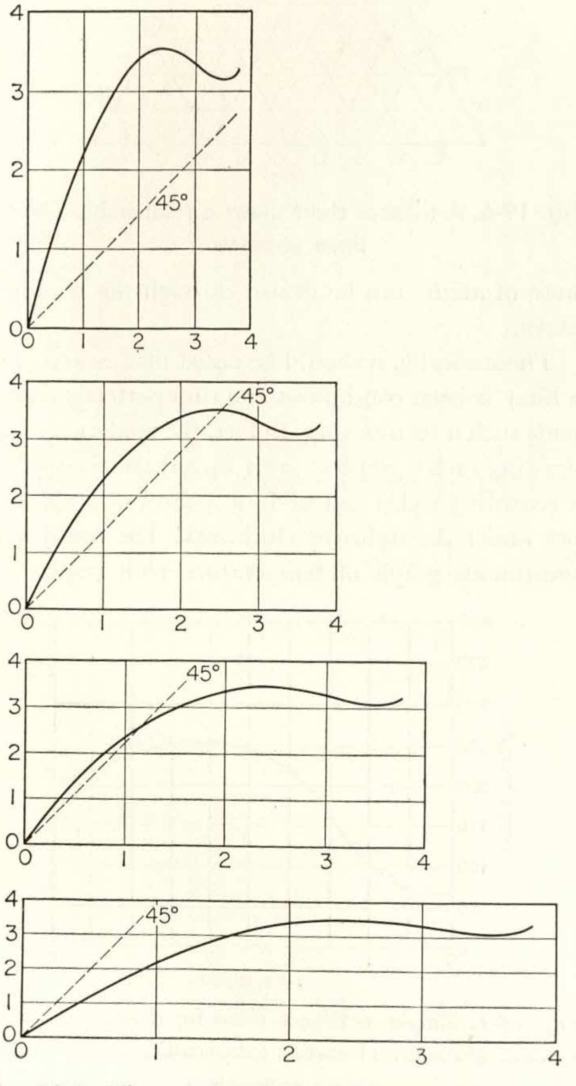


Fig. 19-9. Effect of choice of scale. (From ASA Z15.3.)

time, Fig. 19-8. Here it is quite clear that there was no time when the reactor did not have a temperature and no temperature within the limits involved that did not occur at some time.

19-9. Scale selection. In preparing a graph, a proper choice of scales is extremely important since this governs the apparent rate of change of the dependent variable. The following discussion and Figs. 19-9 and 19-10 are reprinted from the ASA Standard Z15.3, "Engineering and Scientific Graphs for Publications":

> Creating the right impression of the relationship to be shown by a line graph is probably controlled more critically by the relative stretching of the vertical and horizontal scales than by any other feature involved in the design of a graph.
>
> By expanding or contracting the vertical scale relative to the horizontal scale (see Fig. 19-10), a given difference in magnitude of the dependent variable can be made to appear of great or of little significance from the standpoint of (*a*) physical magnitude, (*b*) sensation, or (*c*) value—depending on the author's purpose. A large angle of slope, say over 30° or 40°, is ordinarily interpreted psychologically as of great significance, and a small angle, say less than 5°, of little significance.

19-10. Drawing a rectilinear graph. The principal steps in drawing a rectilinear graph are as follows:

1. Collect, verify, and arrange all data.
2. Select coordinate paper suitable for the data to be shown.
3. Decide on the approximate over-all size of the graph.
4. Place origin at lower left (leaving sufficient room to add lettering later), and draw heavy lines for abscissa and ordinate. Ordinarily, put the independent variable (usually "time") along the horizontal axis and the dependent variable along the vertical axis. An important exception is the "stress-strain" graph, in which the custom is to plot stress (the independent variable) along the vertical axis and strain (the dependent variable) along the horizontal axis.
5. Select suitable scales for both variables in accordance with the principles outlined in Sec. 19-9. In most cases, the scales should permit showing the complete range of data collected. The unit values for each scale should be indicated and preferably

placed so that they can be read from the bottom, not the side.

6. Plot points on the graph in accordance with the data, using small open circles to indicate the points.

7. Draw in the curve, using a heavy firm line. (See the following section for rules on whether the curve should be faired or passed through each of the points.)

8. If more than one curve is shown, label each one or vary their appearance (by using dotted, dashed, dot-dash lines, etc.), and include a key to the meaning of the curves in a clear space on the graph.

9. Label each axis with the appropriate variable, and indicate proper units of measure.

10. Add title at the top of the sheet, boxed in if it lies within the grid area. Include all relevant information such as source, name of observer, date, etc.

11. Ink in all lines and labeling, checking for accuracy and the placement of all points.

19-11. Observed, empirical, and theoretical relationships. In preparing a line graph, curves should be carefully plotted to indicate the exact nature and accuracy of the information presented. Figure 19-11 shows the three basic relationships usually represented, and the following description from "Engineering and Scientific Graphs for Publications" describes how the three types are differentiated:

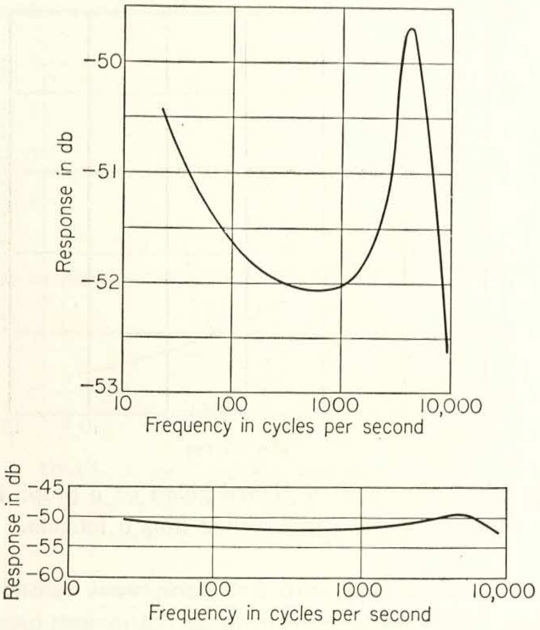


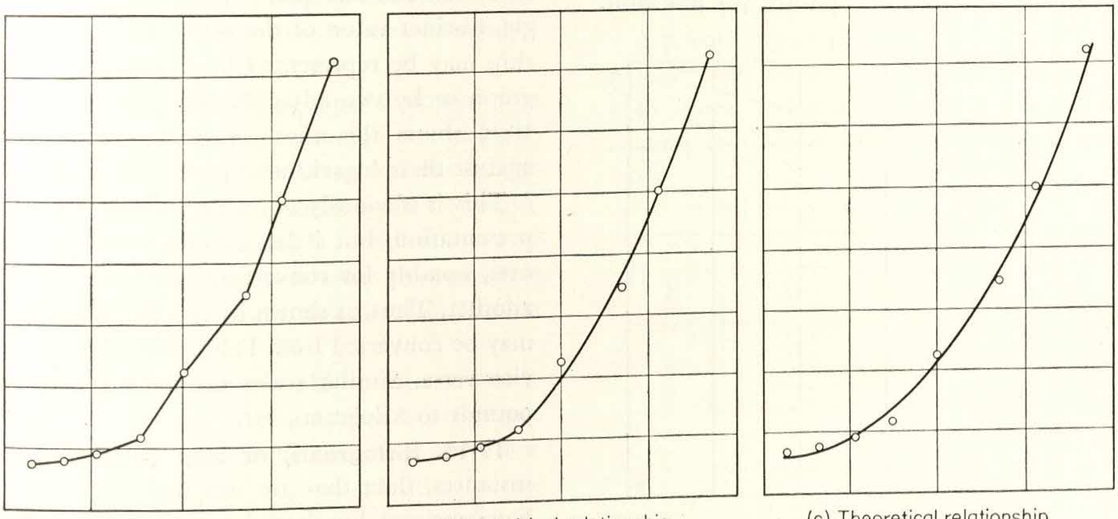
Fig. 19-10. How choice of scale influences the apparent significance of the curve. (From ASA Z15.3)

(*a*) An observed relationship giving a point-by-point plot of the data obtained by experiment or investigation.

(*b*) An empirical relationship giving a curve that reflects the author's interpretation of his series of observations, with or without a point-by-point plot of the observed values.

(*c*) A theoretical relationship giving a curve alone or a curve accompanied by a point-by-point plot of observed values to show consistency of observation with theory.

These basic relationships are discussed in more detail in the following sections.



(a) Observed relationship (b) Empirical relationship (c) Theoretical relationship

Fig. 19-11. The three kinds of relationships commonly presented in graphs.

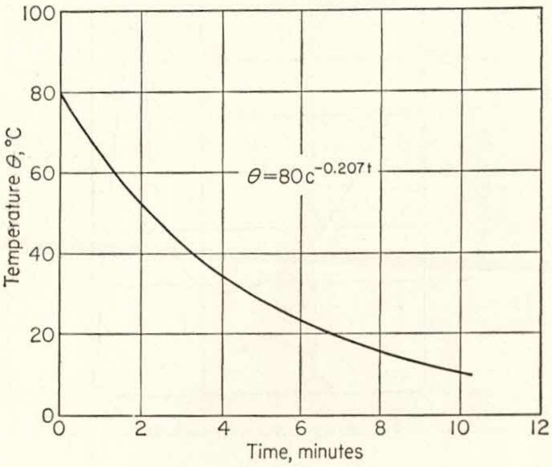


Fig. 19-12. Omission of plotted points on a graph indictates the curve was plotted from a formula.

19-12. Empirical data and continuous relationships. If temperature is measured at various times, a continuous graph is obtained and a smooth curve can be faired through all the points, as was the case in Fig. 19-7. In this case and in most continuous graphs, it is likely that the relationship can be described by a mathematical formula of a form which has been derived by a theoretical analysis of the physical nature of the relationship. The experimental nature of the data is implied by indicating points at which measurements are taken. Thus, by agreement, when a curve shows distinct points, these points have been plotted from experimental data to determine a curve.

On the other hand, when a theoretical curve is presented, that is, one based on, and plotted from, some mathematical formula, points are not indicated, even the ones that were actually computed and used to plot the curve. No one is interested in what arbitrary points were used as long as the curve can be depended upon to represent the formal relationship accurately. Thus Fig. 19-12 indicates by the absence of distinct points that the curve was plotted from the formula.

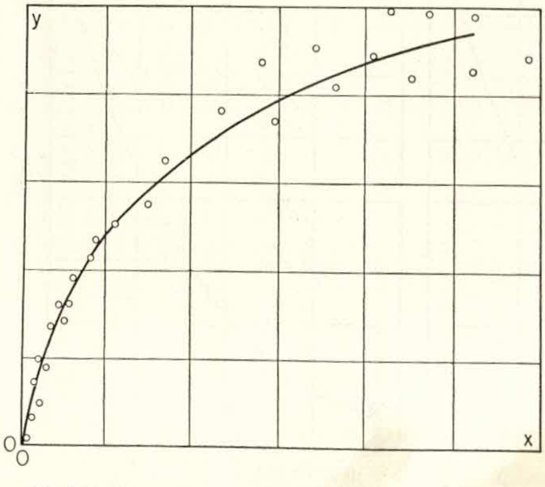


Fig. 19-13. Importance of showing plotted points to indicate reliability of curve.

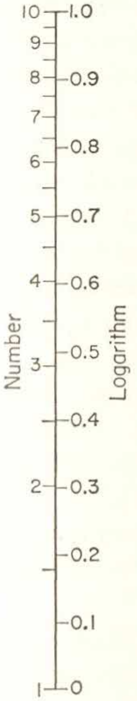
19-13. Experimental error. In laboratory work, because of inaccuracies of measurement or the inability to exclude the effects of extraneous variables, experimental errors inevitably occur so that plotted points do not exactly fit the theoretical curve. This is, in fact, one important reason for showing all plotted points, for they can suggest a great deal about how the experiment was performed, what information is probably accurate, and what information is doubtful.

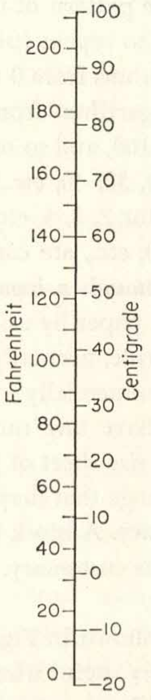
Thus in Fig. 19-13 the experimental points show that, for low values of x many tests have been run, and it is reasonably certain that experiment and theory agree; but for large values of x, only a few tests have been made, and perhaps due to difficulties of measurement or difficulty in excluding extraneous effects, these tests are to some extent mutually contradictory. (x might represent air speed; at very high speeds, for example, near the speed of sound, not many tests have been made because of the difficulty, say, of creating such velocities in a wind tunnel; the results are not consistent because of unstable behavior at such speeds.)

19-14. Adjacent scales. When two quantities are related continuously and in such a way that for every value of one quantity there corresponds a single, distinct value of the other, then this relationship may be represented by a cartesian-coordinate graph or by two adjacent calibrated scales. Figure 19-14 shows the numbers from 1 to 10 graphed against their logarithms by adjacent scales.

This is obviously not a very pictorial method of presentation, but it has certain valuable technical uses, notably for converting one type of unit into another. Thus, as shown in Fig. 19-15, temperatures may be converted from Fahrenheit to centigrade or vice versa. Similar scales can be made to convert pounds to kilograms, etc.

19-15. Histograms, or step graphs. In many instances, data that are not truly continuous may have one variable that, though basically continuous in nature (such as time), is treated in such a way that its continuous nature is not involved. For in-





(Left) Fig. 19-14. Conversion of numbers to logarithms (and vice versa) by use of adjacent scales.

(Right) Fig. 19-15. Use of adjacent scales to show relationship between different temperature scales.

stance, suppose we plot the number of automobiles manufactured for selected years (Fig. 19-16). Note that time in this instance is not really continuous, for a new beginning is made each year. Thus we should not graph Fig. 19-16 by drawing a smooth curve as in Fig. 19-8. To do so would imply that every point on the curve represented an instant in time. One could not, for instance, determine from the graph the number of automobiles sold on July 1 of any year.

19-16. Pseudocontinuous graphs. Suppose that an anthropologist measured the weight of every person in the United States and that he fed this data to a machine which sorted out the weights in ascending magnitudes and attached a serial number to each weight. Then suppose that the machine plotted the results on a graph and that Fig. 19-17 is the result.

The shape of the graph would be approximately as shown: There are a few babies born whose weights are nearly negligible, and there are a few fat people whose weights are very considerable indeed, but most of us weigh between 100 and 200 lb.

Now this is not a *continuous* graph. It is 160 million distinct points, one for each person in the country. However, the drawing of the continuous curve does give a picture of human weight distribution of interest and meaning, which justifies its use. It is in effect a pseudocontinuous graph.

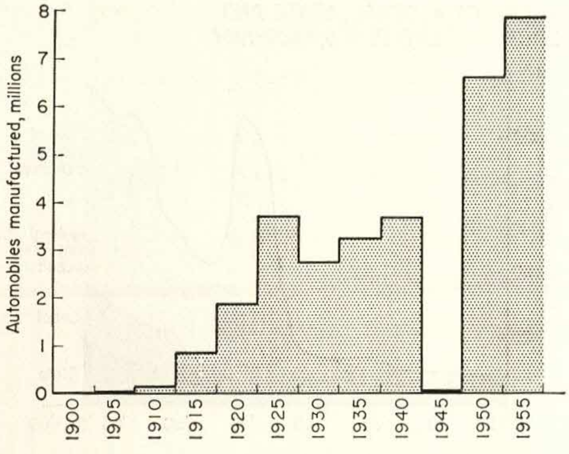


Fig. 19-16. A step graph presents statistical information in a series of isolated measurements; it does not show a continuous set of data.

The student should distinguish carefully between bar graphs, step graphs, continuous graphs, and pseudocontinuous graphs. Graphs are more frequently misread because of a failure to make this distinction clear than from any other cause.

19-17. Area charts. An area chart is a special type of shaded line graph that is most commonly used to show changes in the component parts of a total (see Fig. 19-18). This chart should be used only when it is desired to focus attention on the distance between curves since the distance of the curves —other than the lowest one—from the base is not relevant.

A peculiarity of this type of chart is that an irregular layer in the middle will cause those above it to appear irregular also and perhaps give a misleading impression. Where feasible, therefore, the

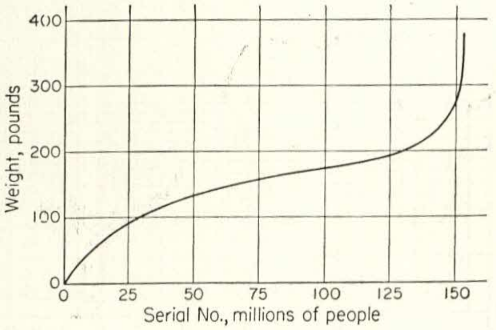


Fig. 19-17. Pseudo-continuous graph used to show distribution.

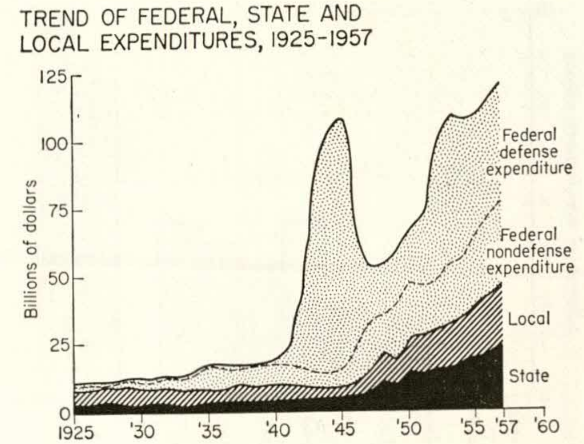


Fig. 19-18. Area charts have heaviest shading at bottom, lightest at top. Note use of dashed line to separate the two parts of the shaded area at top.

most irregular layer should be placed at the top of the chart. Another disadvantage is that the bottom layer is the only one that can be read accurately. In applying shading, it is best to start with the darkest area at the bottom and graduate toward the lighter tones at top; otherwise, the chart acquires a disturbing top-heavy appearance.

19-18. Logarithmic charts. A logarithmic chart is one in which both the horizontal and vertical axes are ruled in divisions proportional to the logarithms of the numbers on the scale (see Fig. 19-19). This type of chart is used primarily for calculation and for the solution of engineering problems and is rarely prepared to present factual information to others.

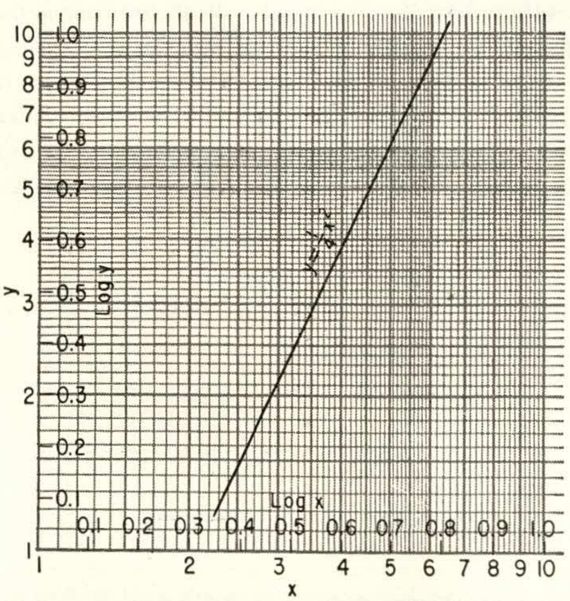


Fig. 19-19. Logarithmic chart of the equation $y = \frac{1}{4}x^2$

The pattern of the gridwork of Fig. 19-19 can be made to repeat itself by extending the scales. Thus logarithms from 0 to 1 represent numbers from 1 to 10, logarithms from 1 to 2 represent numbers from 10 to 100, and so on; within this span, the gridwork for 20, 30, 40, etc., will repeat that of the previous span for 2, 3, 4, etc. The groups 0.1 to 1, 1 to 10, 10 to 100, etc., are consequently called "cycles."

Although a logarithmic scale can be marked on blank paper by using the logarithmic divisions on a slide rule, normally logarithmic charts are prepared on commercially available graph paper. This paper may have any number of cycles. However, for a given size sheet of paper, each added cycle increases the range that may be represented at the expense of accuracy. A block of four cycles, two in each direction, is customary. This is called "two-cycle" graph paper.

As shown in Fig. 19-19, a logarithmic chart is extremely useful when it is necessary to plot an equation like $y = ax^b$ (x not being equal to zero) because the graph will be a straight line whenever the dependent variable is proportional to a function of a constant power of the independent variable. Thus curves whose representation in rectangular coordinates would be complicated and time-consuming, can be plotted as straight lines on logarithmic paper when only two points are known. An additional advantage of logarithmic paper is, of course, that large numbers can be shown by short distances on the graph.

19-19. Semilogarithmic charts. Charts of this type have one axis divided uniformly and one logarithmically. Usually the uniform scale divisions are used for the independent variable and are laid off on the horizontal axis. With semilogarithmic ruling, the slope of the curve at a given point measures the *rate* of increase or decrease, and this chart is therefore particularly useful for predicting trends, growth, etc. (see Fig. 19-20). On semilogarithmic paper, the graph will result in a straight line whenever the increments of the dependent variable increase in geometric progression while the increments of the independent variable increase arithmetically.

19-20. Polar charts. Polar charts are plotted on regularly spaced circular coordinate rulings. They are most commonly used to show the distribution of light, heat, etc., radiating from a given source (see Fig. 19-21).

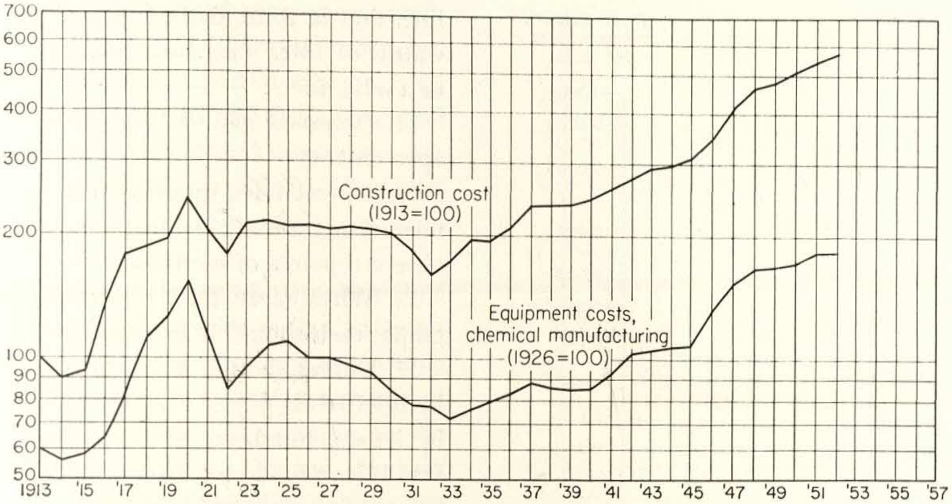


Fig. 19-20. Semilogarithmic charts are useful to show *rate* of growth.

19-21. Drafting principles. Great care is required in drafting charts and graphs to ensure accurate and unambiguous presentation of data. The following list of drafting principles is based on the suggestions offered in ASA Z15.3:

1. The simpler the graph, the smaller it may be; the more important it is, the larger it may be; a balance should be reached between these two factors.
2. Ordinarily, not more than three or four curves should be shown on the same graph.
3. All lettering and numbers should be placed to read from the bottom or right-hand side of the graph.
4. Use standard abbreviations where space is limited.
5. Include the zero line where visual comparison of plotted magnitudes is important.
6. Except when charts are drawn on graph paper, scale captions and values should be placed outside the grid area.
7. If two related curves with different vertical scales are to be shown on the same graph, place one vertical scale at the left and the other at the right.
8. The scale caption should indicate both the variable measured and the unit of measure, for example, "Resistance, ohms."
9. For arithmetic scales, the scale numbers shown on the graph and the space between coordinate rulings should preferably correspond to 1, 2, or 5 units of measure, multiplied or divided by 1, 10, 100, etc.
10. Avoid the use of many digits in scale numbers by employing a power of 10 as a factor in the scale values or by using an appropriate note in the scale caption, for example, "Resistance, thousands of ohms."
11. Coordinate rulings should be limited to those necessary to guide the eye in making a reading to the desired degree of approximation. Closely spaced rulings should be avoided except for computation charts. Coordinate rulings should be the narrowest in width of any lines of the graph.
12. Curves are preferably represented by solid lines.
13. When more than one curve is to appear on a graph, relative emphasis or differentiation of the curves may be secured by using different types of

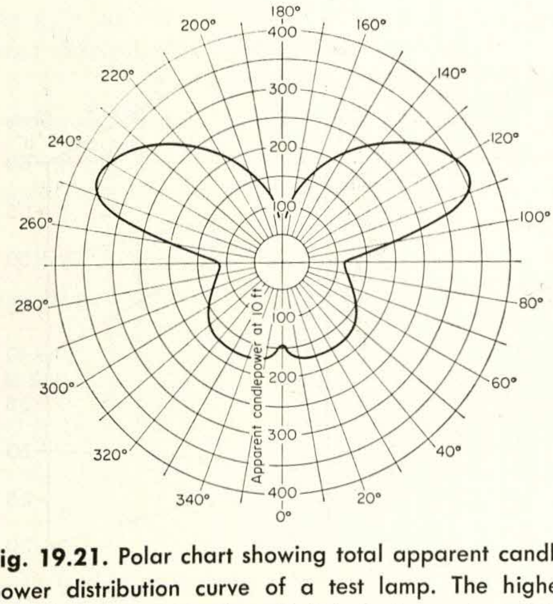


Fig. 19.21. Polar chart showing total apparent candlepower distribution curve of a test lamp. The highest light intensity is at 115° and 245°; the lowest is at 180°.

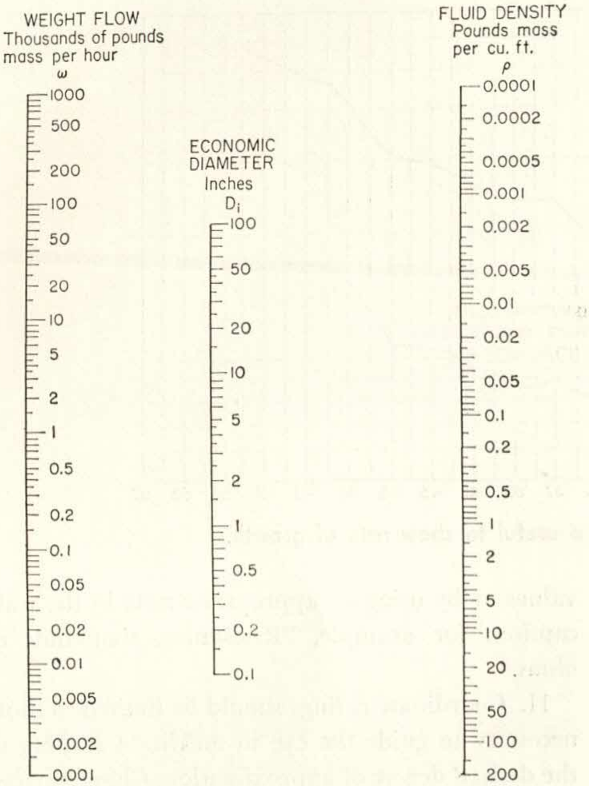


Fig. 19-22. Nomograph for determining economic pipe diameter for fluids of various densities and mass. Connect values of w and p to obtain economic pipe diameter.

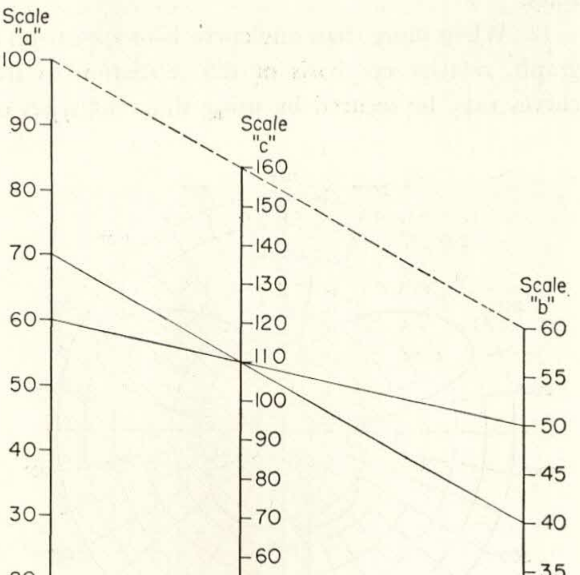


Fig. 19-23. Construction of a nomograph for the equation $a + b = c$.

line, that is, solid, dashed, dotted, etc., or different widths of line. The most important curve should be a solid line.

14. Observed points should be designated by open circles.

15. Open circles, squares, and triangles should be used rather than filled-in symbols to differentiate observed points of several curves on a graph.

16. When more than one curve is shown on a graph, each should bear a suitable designation.

17. Curves should, if practicable, be designated by brief labels placed close to the curve rather than by letters, numbers, or other devices requiring a key. Where necessary, a short straight arrow should be drawn to connect label and curve.

18. If a key is used, it should be placed within the grid in an isolated position and enclosed by a light line border.

19. The title should be as clear and concise as possible. Extra explanatory material should be added as a subtitle.

20. Titles and subtitles should not be placed within the grid area of the graph.

21. For lettering, use vertical gothic capitals.

19-22. Nomographs. A *nomograph*, or *nomogram,* is a type of graph designed exclusively for simplifying or eliminating mathematical calculation. It is a form of alignment chart that, with the aid of a straightedge, permits reading the value of a dependent variable when the values of the independent variables are known. It is therefore not a "presentation chart" but is instead a valuable working tool for the engineer or for the person whose knowledge of mathematics is scanty. Figure 19-22 shows a typical nomograph that was constructed to provide a simple means of calculating economic pipe diameter for the streamline-flow region of an industrial piping system.

19-23. Construction of a nomograph. In order to construct a nomograph, it is necessary to know the range of each variable and the equation that relates them. For example, a nomograph for the equation $a + b = c$, where values of a range from 0 to 100 and values of b from 20 to 60, is constructed as follows (see Fig. 19-23):

1. Draw two parallel vertical lines a convenient distance apart, using any convenient length for each. The ends of the verticals need not align.

2. Identify one vertical as the *a* scale, and mark off equally spaced divisions in ascending order, corresponding to the range of the variable *a*.

3. Identify the other vertical as the *b* scale, and mark off convenient equally spaced divisions to correspond to the range of the variable *b*. The values should increase in the same direction as those on the *a* scale.

4. Now, to locate the *c* scale, draw a light line connecting a value on the *a* scale with a value on the *b* scale. Then draw a second line connecting two other values that total the same as the sum of the first two values selected (for example, in the figure, the lines 60-50 and 70-40). Repeat this with another pair of lines. A line drawn through the two points of intersection is the *c* scale.

5. To calibrate the *c* scale, first draw a line connecting the lowest value on each scale. This establishes the starting point, or lowest value, of the *c* scale (in this case, 20). Repeat this process with maximum values of *a* and *b* to establish the upper end of the *c* scale. Then mark off on the *c* scale a convenient number of equal divisions, and indicate values.

6. Check the accuracy of the construction by connecting with a straightedge various values of the *a* and *b* scales and reading off the proper sum on the *c* scale.

This device may also be used to solve for the unknown side of a right triangle by calibrating the scales in accordance with the formula $a^2 + b^2 = c^2$. A nomograph for subtraction may be constructed by laying out the *a* and *b* scales so that the values increase in opposite directions.

If the scales are calibrated logarithmically instead of uniformly, multiplication can be performed with this device (see Fig. 19-24). Division is performed similarly by laying out the scales logarithmically in opposite directions.

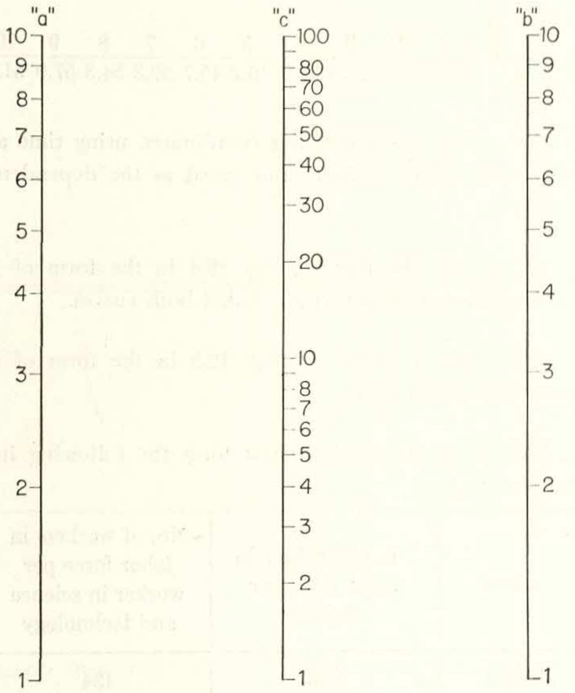


Fig. 19-24. Nomographic scales calibrated logarithmically to perform multiplication.

A nomograph for an equation like $2a + 3b = c$, which contains constants in addition to the variables, is constructed in much the same way as that shown in Fig. 19-23. There is one important difference, however: The *a* and *b* scales are exactly the same as before, but the *c* scale is located and calibrated to show the effect of the coefficients of *a* and *b*. In the preceding example, the intersection of the lines 60-50 and 70-40 established the location of the *c* scale and one of its values. For the equation $2a + 3b = c$, the coefficients must be allowed for so that the initial line 60-50 is actually

$$2 \times 60 + 3 \times 50 = 270$$

A line to intersect with this would not be the 70-40 line (since $2 \times 70 + 3 \times 40 = 260$) but instead might be a line connecting $a = 30$ and $b = 70$ since

$$2 \times 30 + 3 \times 70 = 270$$

This establishes the 270 value on the *c* scale; the rest of the construction proceeds as before.

PROBLEMS

19.1. Draw a bar or pie chart to show the chemical composition of the mineral zircon, using the following data:

Chemical Analysis of Zircon, Weight per Cent

ZrO_2	65
SiO_2	33.60
Fe_2O_3	0.15
Al_2O_3	1.0
TiO_2	0.25

19.2. The acceleration curve for a new type of torque-converter transmission is as follows:

Time, sec	0	1	2	3	4	5	6	7	8	9	10
Speed, mph	0	8.9	17.6	26.0	33.7	40.2	45.7	50.3	54.3	57.9	61.2

Plot the data on rectangular coordinates, using time as the independent variable and speed as the dependent variable.

19.3. Show the data of Fig. 19.4 in the form of a rectangular coordinate chart. Label both curves.

19.4. Show the data of Fig. 19.5 in the form of a grouped-column chart.

19.5. Show in suitable chart form the following information:

Year	No. of workers in labor force per engineer	No. of workers in labor force per worker in science and technology
1890	863	434
1900	709	322
1910	445	201
1920	326	145
1930	226	108
1940	185	97
1950	113	59

19.6. The following data show water use in this country from 1900 to 1950, with estimated consumption for 1960 and 1970. Present this information in a chart, choosing the form that you think would be most effective.

Total Water Use, 1900 to 1970, (In billions-of-gallons-daily average)

Year	Total	Irrigation	Public water	Personal & industrial
1900	40.19	20.19	3.00	17.00
1910	66.44	39.04	4.70	22.70
1920	92.34	55.94	6.00	30.40
1930	110.50	60.20	8.00	42.30
1940	135.43	71.03	10.10	54.30
1950	203.10	100.00	14.10	89.00
1960	312.45	134.95	22.00	155.50
1970	404.51	159.01	27.80	217.70

SOURCE: Department of Commerce, Business and Defense Services Administration.

19.7. You are to choose the more economical source of heating power, electricity or gas, for a new industrial plant that may be located in any one of the cities listed in the following table. Prepare a suitable chart that compares the dollar rates in each city (conversion formula: 1 Btu = 0.000293 kwhr).

Electricity versus Gas Prices, Selected Cities 1956

City	100 kwhr	10 therms (1 therm = 100,000 Btu)
Atlanta	\$3.72	\$1.62
Chicago	3.78	1.93
Detroit	3.85	1.68
Houston	2.83	1.40
New York	4.73	2.94
Pittsburgh	3.95	1.59
San Francisco	3.64	1.25
Seattle	2.52	4.27

SOURCE: Department of Labor, Bureau of Labor Statistics.

19.8. In order to show the rate of growth of various typical industries, plot the following data on a semilogarithmic chart, where the figures represent an index of industrial capacity based on 1950 = 100.

Industry	1951	1952	1953	1954	1955	1956	1957	1958*	1961*
Iron and steel	103	111	117	119	123	128	137	141	148
Machinery	113	123	130	137	147	165	177	184	202
Chemicals	110	122	134	142	152	163	176	188	224
Rubber	104	111	118	126	137	145	148	151	162
Petroleum refining	104	109	117	122	126	132	136	139	146
Textiles	105	107	112	111	118	123	125	128	133

* Estimated figures.

19.9. Construct a nomograph for $x + y = z$, where the range of x is 5 to 65 and the range of y is 2 to 28.

19.10. Construct a nomograph for $x - y = z$ where the range of x is 3 to 8 and the range of y is 0.5 to 2.

19.11. Construct a nomograph that will give the hypotenuses of right triangles whose legs vary from 2 to 10 in. on one side and from 4 to 16 on the other.

19.12. Construct a nomograph for $xy = z$ where the values of x range from 0.2 to 1.8 and y from 0.325 to 0.750.

19.13. Construct a nomograph for $2x/3y = z$ where the values of x range from 100 to 1200 and y from 10 to 25.

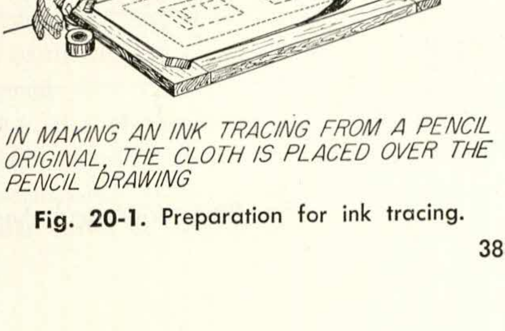
Chapter 20

INKING PROCEDURE

The purpose of this chapter is to assist the student or beginning draftsman in preparing a drawing from which a successful print can be made by any of the numerous methods of contact printing in use today. In practically all cases, the working drawing used in the machine shop is a reproduction of an original prepared in the drawing and design room. The original may be either a pencil or an ink drawing executed on tracing paper or tracing cloth. The pencil drawing is prepared directly on the tracing sheet. The ink drawing, on the other hand, is usually prepared by first making a pencil drawing on ordinary drawing paper and then tracing it in ink on transparent tracing paper or cloth placed over the original (see Fig. 20-1). Ink drawings are also prepared by working on the transparent surface with pencil and then inking over the pencil lines.

20-1. Making a print. The basic procedure in making any contact print is to expose the tracing and contact paper to light from one of four main sources—sunlight, arc light, low-pressure tube light, and high-pressure tube light. The success of the print is dependent on the intensity of light and the length of the exposure, the ink or pencil technique employed in making the original drawing (width and firmness of lines, erasures, etc.), the kind of paper or cloth on which the original has been prepared, and the image-fixing medium employed with the contact paper. There have been many improvements in the mechanical equipment used in print making from tracing cloths and papers since the first blueprint was produced many years ago. Regardless of this fact, however, the success of all methods depends to a large degree on the quality of the original drawing used in making the print.

20-2. Selecting the tracing paper or tracing cloth. Selection of the proper tracing paper or tracing cloth is one of the most important factors contributing to successful print making. There are two types of tracing paper available on the market. The so-called "natural" paper is, as its name implies, naturally transparent; vellum paper, on the other hand, is transparentized by artificial meth-



IN MAKING AN INK TRACING FROM A PENCIL ORIGINAL, THE CLOTH IS PLACED OVER THE PENCIL DRAWING

Fig. 20-1. Preparation for ink tracing.

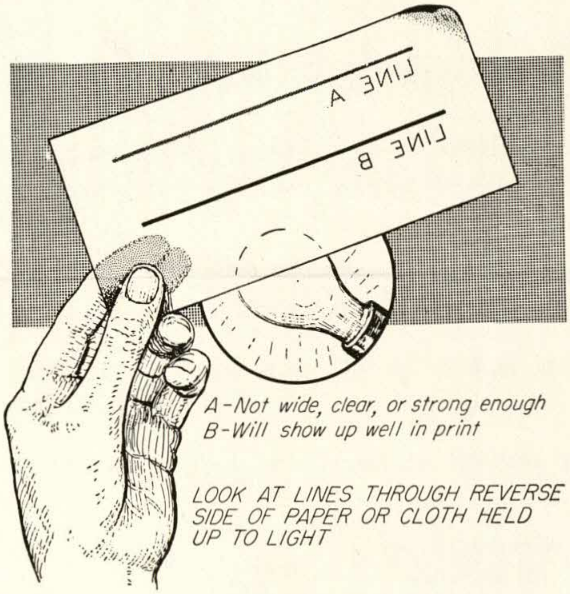

LINE A
LINE B
A-Not wide, clear, or strong enough
B-Will show up well in print
LOOK AT LINES THROUGH REVERSE SIDE OF PAPER OR CLOTH HELD UP TO LIGHT

Fig. 20-2. Testing for line quality.

ods. The natural papers will preserve their transparent quality indefinitely, while some of the vellums may lose it in a very short time. Both take ink or pencil equally well. Whichever type is selected, the paper should be checked for the following qualities: It should have 100 per cent rag content (the strength of the paper depends on its rag content). Check its cloud-producing deficiencies by holding it up to a strong light; if light and dark areas show up, they will be transmitted to the print. Test its ability to withstand erasure; if the surface breaks down too easily, repenciling or re-inking may be impossible. Feel its tooth qualities; if the surface is too rough, ragged lines and excessive dulling of the pencil will result; if the surface is too smooth, a clean, dark, and crisp (good-printing) line cannot be produced. If possible, check with other users on the ability of the paper to withstand discoloration. Because of their general freedom from cloudiness and better transparency, the vellums appear to be more in demand; the heavier weights in the natural papers are longer-lived, however, and are perfectly satisfactory for engineering drawings.

20-3. Tracing cloth. Although tracing cloth is more expensive than tracing paper, it is more durable and frequently more satisfactory for ink work and for drawings that are to be preserved over a number of years. Most tracing cloths permit the use of either pencil or ink, and any properly

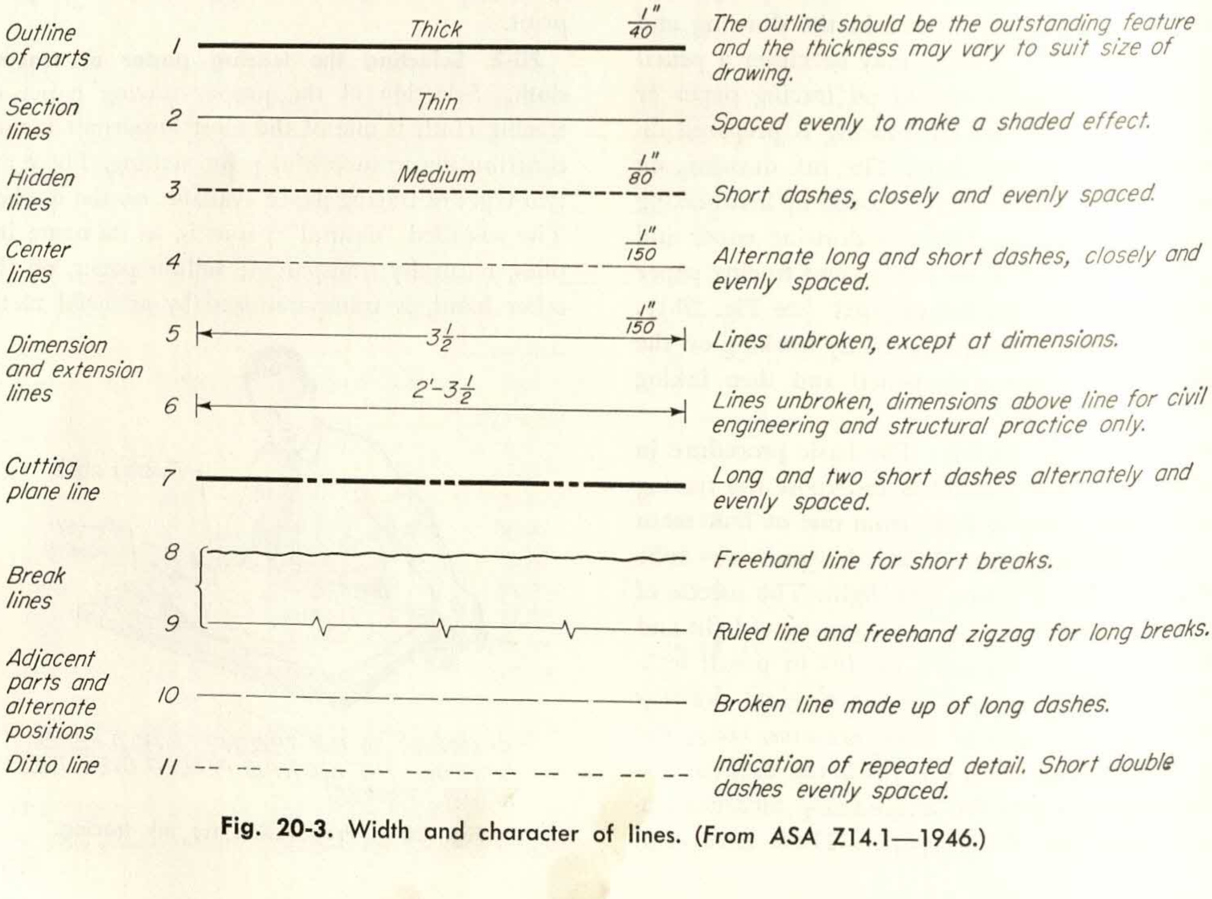

Outline of parts
1
Thick
1"/40
The outline should be the outstanding feature and the thickness may vary to suit size of drawing.
Section lines
2
Thin
Spaced evenly to make a shaded effect.
Hidden lines
3
Medium
1"/80
Short dashes, closely and evenly spaced.
Center lines
4
1"/150
Alternate long and short dashes, closely and evenly spaced.
Dimension and extension lines
5
3½
1"/150
Lines unbroken, except at dimensions.
6
2'-3½
Lines unbroken, dimensions above line for civil engineering and structural practice only.
Cutting plane line
7
Long and two short dashes alternately and evenly spaced.
Break lines
8
Freehand line for short breaks.
9
Ruled line and freehand zigzag for long breaks.
Adjacent parts and alternate positions
10
Broken line made up of long dashes.
Ditto line
11
Indication of repeated detail. Short double dashes evenly spaced.

Fig. 20-3. Width and character of lines. (From ASA Z14.1—1946.)

surfaced linen tracing cloth that is reasonably wax-free and moisture-resistant will give satisfactory prints from originals executed in either manner. Of the two types available, the blue-tinted and the white, the white is more popular because it appears to be easier on the eyes and will take both pencil and ink lines with almost equal success. Leads of a good quality ranging from an HB to a 3H will produce acceptable results, but the greater opacity of a good India ink ensures sharper and more even lines on the print. Tracing cloths have a dull side and a glossy side. Pencil work is done on the dull side. Ink work can be done on either the glossy or dull surfaces.

20-4. Line intensity. In preparing pencil drawings for reproduction, a comparatively soft pencil should be used. The harder pencils (3H to 9H) have a tendency to produce light, weak lines and dig into the drawing surface, and therefore their use is not recommended. For ink work, the ink selected (either black or colored) should be sufficiently opaque to ensure the intensity of line necessary to obtain a clear and sharp print. In general, the line work on tracings should be wider (and blacker when pencil is used) than for ordinary drafting. Often a pencil line (and at times even an ink line) will appear firm, strong, and dark enough on the surface of the sheet when attached to the drawing board, but inspection by reversing the drawing and looking at the line toward a strong light will reveal that its light-stopping properties are insufficient to produce satisfactory results (see Fig. 20-2).

20-5. Standards for ink lines. Figure 20-3 shows the ASA-recommended relative line widths for the preparation of inked drawings. The widths of the lines most commonly employed in drafting have been given also. In general, a good rule to follow is to make center lines, dimension lines, extension lines, and section lining the narrowest, or thinnest, on the sheet; the hidden lines of the object twice as wide as the center lines; and the visible object lines twice as wide as the hidden lines.

20-6. Filling the ruling pen. Remove the stopper from the ink bottle with a turning motion to avoid snapping off the head. Close the blades of the pen, and pass the dropper between them near the point formed by the nibs, leaving a drop of ink about ¼ in. above the point (see Fig. 20-4). Be sure that the outside surfaces of the blades are not smeared with ink. If they are, wipe the pen clean of all ink and repeat the operation.

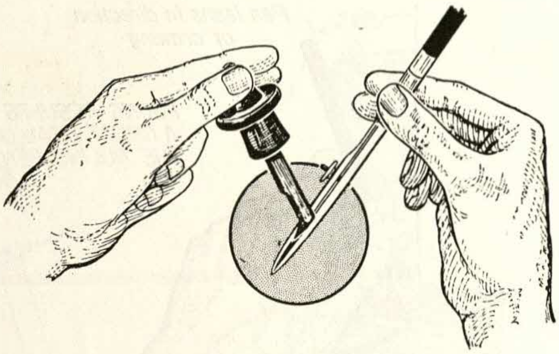


Fig. 20-4. Filling the ruling pen.

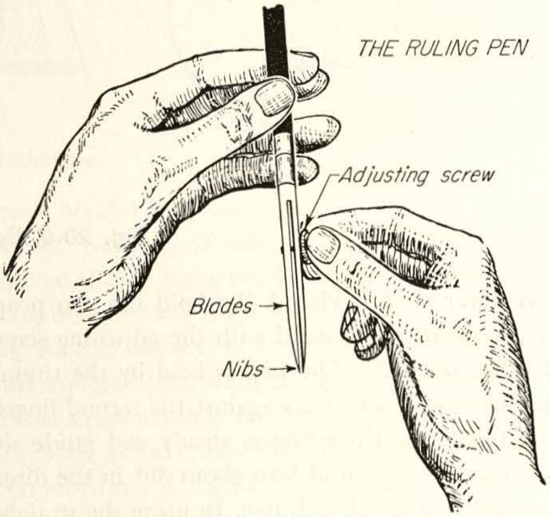


Fig. 20-5. Adjusting the pen.

20-7. Adjusting the pen. The width of the ink line depends upon the separation of the pen's blades at the points. The closer together, the narrower the line; the farther apart, the wider the line. The blades are spread apart or brought together by manipulating the adjusting screw located just above the points (Fig. 20-5). To adjust the pen to a desired line width, draw trial lines on a piece of scrap paper or cloth (identical with the drawing sheet being used) until the desired line is secured. Trial lines may also be drawn on the outside of the margin along which the sheet is to be trimmed.

20-8. Use of the ruling pen. The ruling pen is always used in conjunction with a guiding instrument, such as the T square, triangles, or irregular curve, to "ink in" or trace penciled lines.

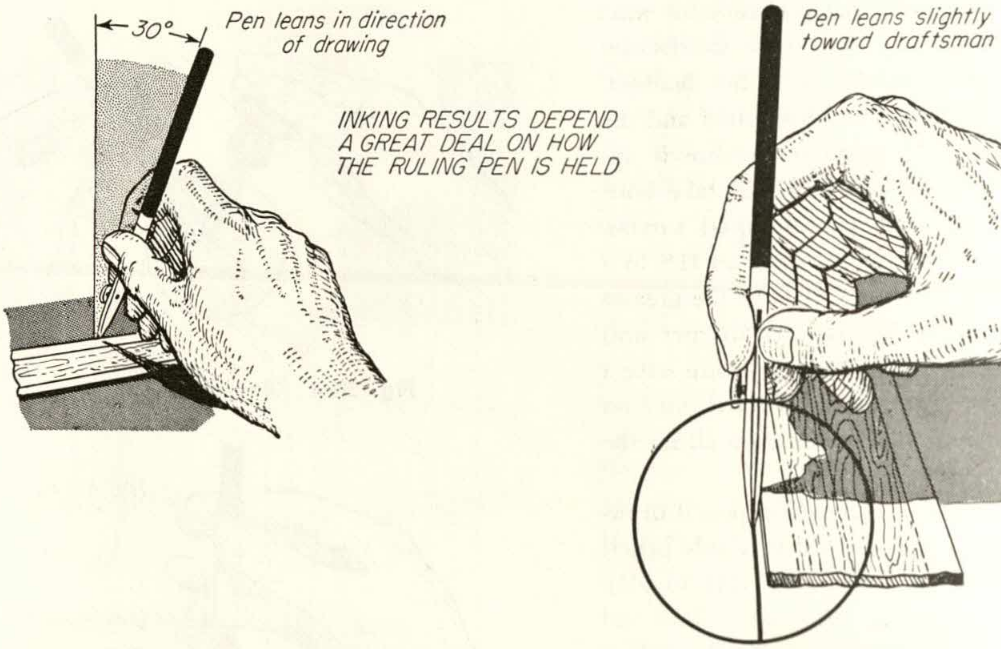

30°
Pen leans in direction of drawing
INKING RESULTS DEPEND A GREAT DEAL ON HOW THE RULING PEN IS HELD
Pen leans slightly toward draftsman

Fig. 20-6. Holding the ruling pen.

It is never used freehand. To hold the pen properly, place it in the hand with the adjusting screw pointing outward. The pen is held by the thumb and first finger and rests against the second finger. The third and little fingers steady and guide the hand. The pen should lean about 30° in the direction of the line being drawn. In using the straightedge, the pen should lean slightly toward the draftsman (see Fig. 20-6). Should the ink fail to flow after filling the pen, draw the point across the nail of the thumb or a saliva-moistened paper scrap. This should start the pen unless the nibs are improperly shaped.

20-9. Inking technique. Many of the unfortunate occurrences in inking procedure are the result of improper manipulation of the pen, unwillingness on the part of the draftsman to allow enough time for the ink to dry, incorrect treatment of line intersections and junctures, or carelessness in regard to line widths.

In tracing or inking a pencil line, the ink line should be centered over the pencil line as shown in

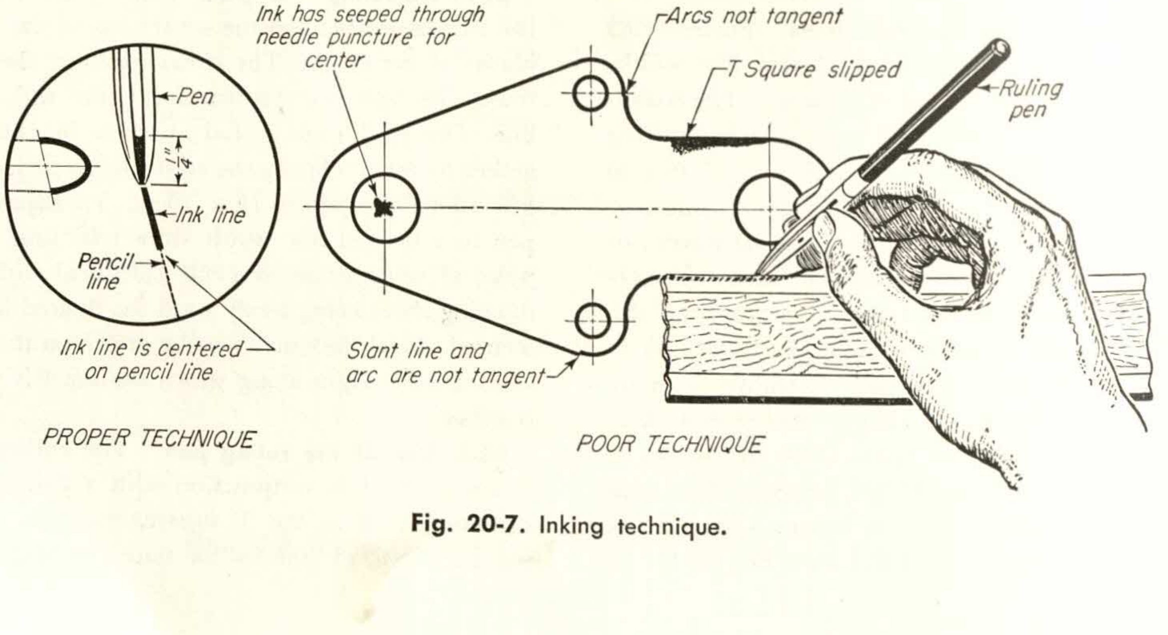

Pen
1/4"
Ink line
Pencil line
Ink line is centered on pencil line
PROPER TECHNIQUE
Ink has seeped through needle puncture for center
Arcs not tangent
T Square slipped
Ruling pen
Slant line and arc are not tangent
POOR TECHNIQUE

Fig. 20-7. Inking technique.

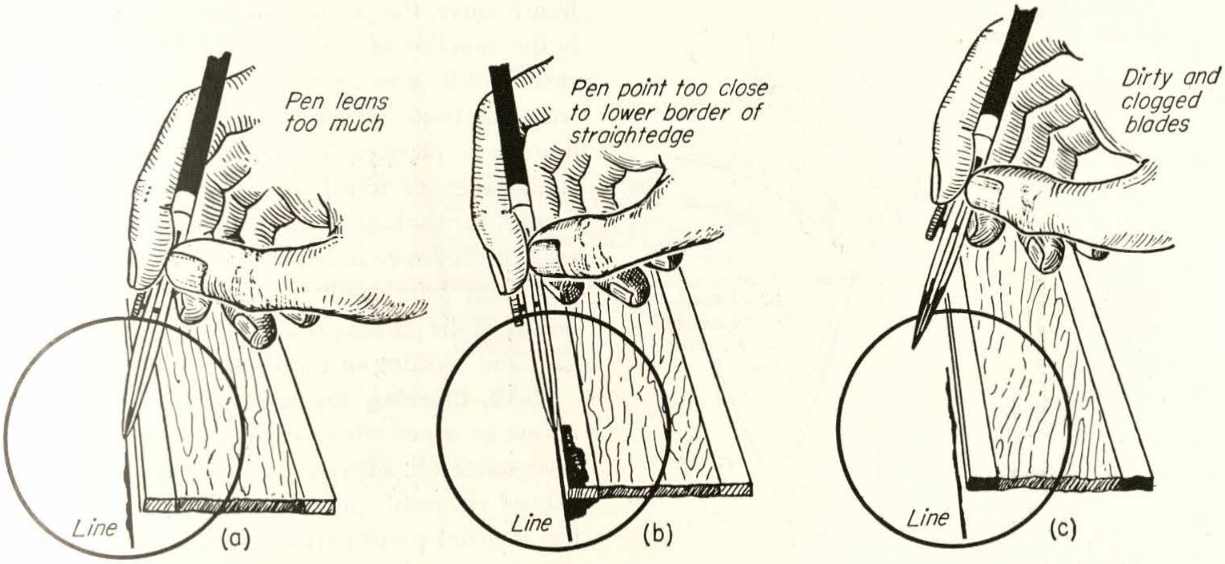


Fig. 20-8. Inking technique.

Fig. 20-7. Careful attention to this in inking circles, arcs, irregular curves, and straight lines will assure proper junctures at tangent points. When removing the straightedge from a newly drawn line, avoid pushing it toward the line in the slightest degree; otherwise it will cause the mishap shown in the figure. Ink all center lines for circles and arcs first. If this is not done, the center lines will blot at their intersections when inked over the hole in the drawing sheet made by the compass point. If the pen is held so that it leans too far toward the draftsman, an irregular and uneven line will result because only one nib will touch the drawing surface (see Fig. 20-8*a*). The pen should not be held so that it leans too far away from the draftsman, because thus the ink will run under the working edge as shown in Fig. 20-8*b*. If dried ink or dust and particles from the wiping cloth are permitted to accumulate on the pen, a ragged, uneven line such as that shown in Fig. 20-8*c* will result. Too much ink in the pen will cause a drop to form that will blot the drawing (Fig. 20-9*a*). If the ink carried in the pen is insufficient to finish the line, it will appear split at the extremity (Fig. 20-9*b*).

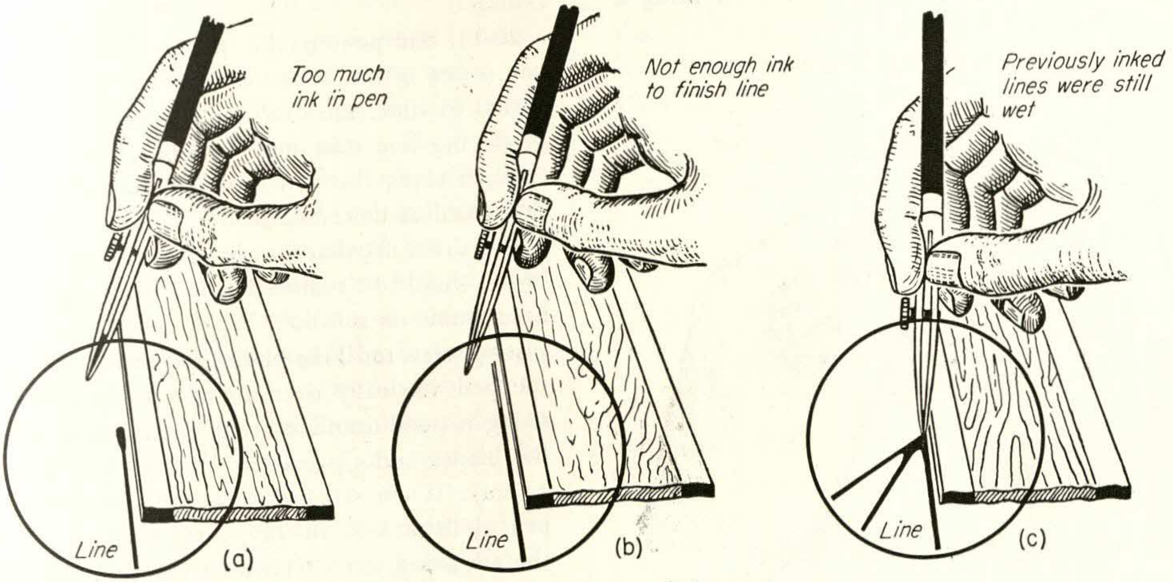

Too much ink in pen
Line
(a)
Not enough ink to finish line
Line
(b)
Previously inked lines were still wet
Line
(c)

Fig. 20-9. Inking technique.

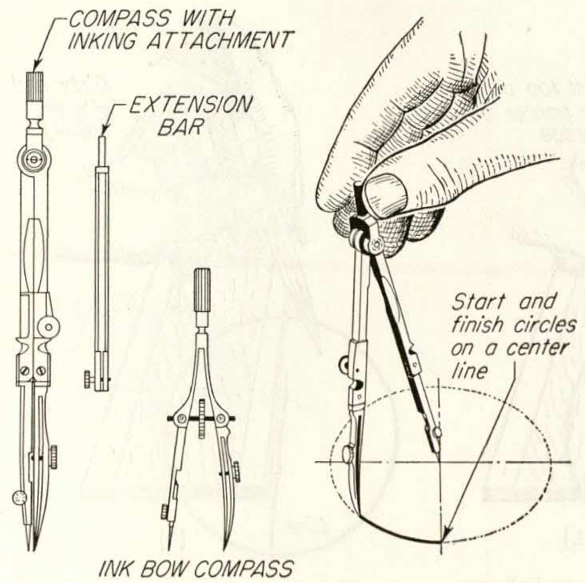

COMPASS WITH INKING ATTACHMENT
EXTENSION BAR
Start and finish circles on a center line
INK BOW COMPASS

Fig. 20-10. Use of the compass.

Sharp corners and intersections are impossible unless the previously inked lines are completely dry (Fig. 20-9*c*).

The large compass with the ruling-pen attachment is employed in inking circles and arcs up to 9 or 10 in. in diameter. For larger circles, the ruling-pen attachment and the interchangeable compass joint with extension bar may be used. The ink bow compass will serve for the inking of small circles and arcs (Fig. 20-10).

The various types of french curves are used to ink noncircular and irregular curves. In using a french curve, the pen should lean only very slightly in the direction of the line being drawn; otherwise, there will be a tendency for the pen point to stray from the route of the guiding pencil line. Many draftsmen place a triangle under the guiding straightedge or french curve, with the upper instrument's working edge extended just over the edge of the lower instrument, in order to keep the pen point from coming in contact with the lower border of the guiding instrument and causing dragging and blotting of the lines.

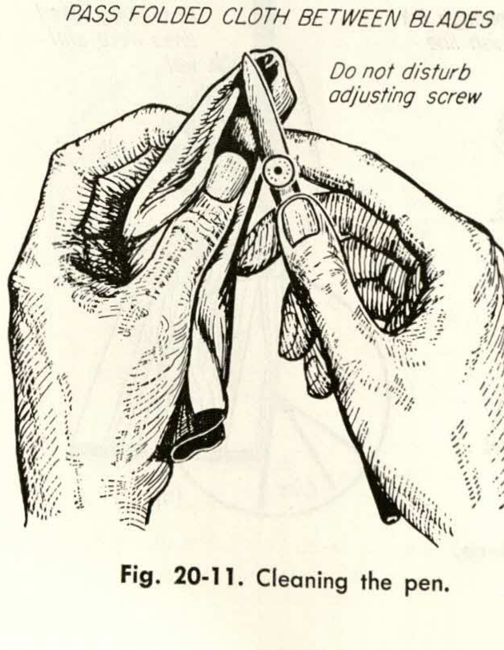

PASS FOLDED CLOTH BETWEEN BLADES
Do not disturb adjusting screw

Fig. 20-11. Cleaning the pen.

20-10. Cleaning the pen. A new pen should always be wiped with a clean cloth moistened with a vegetable oil, such as olive or corn oil, and then rubbed vigorously until dry. This will prevent rusting of metal parts, particularly the threads on the adjusting screw, and will not affect the functioning of the pen in any way. To obtain the best results while the pen is in use, it should be wiped clean before each refilling. If the draftsman is interrupted, the pen should be wiped dry before it is placed aside, because dried-ink accumulations mixed with fresh ink will cause annoying variations in the width of lines. The setting of the pen point need not be changed with each wiping if a folded linen cloth is passed carefully between the nibs and then pulled gently through (see Fig. 20-11). When the pen is to be put away for the day, it should be thoroughly cleaned by washing it in a weak solution of ammonia (the household preparation).

20-11. Sharpening the pen. Sometimes, if a pen is new or has been used constantly over a long period of time, the draftsman may have difficulty producing fine thin lines or lines of even width. In such cases, the pen should be reshaped or resharpened as described below.

Any dried ink that may have accumulated on the blades should be removed by washing the pen in a mild ammonia solution. When clean, turn the adjusting screw until the blades just touch. Then hold the pen vertically over a fine-grained stone, and swing it pendulumlike across the stone to sharpen the blades and to equalize their length (see Fig. 20-12*a*). When satisfied with the result, hold the pen as illustrated in (*b*), and, without touching the adjusting screw, continue the sharpening procedure with a slight circular motion until the points present the elliptical shapes shown at (*c*)

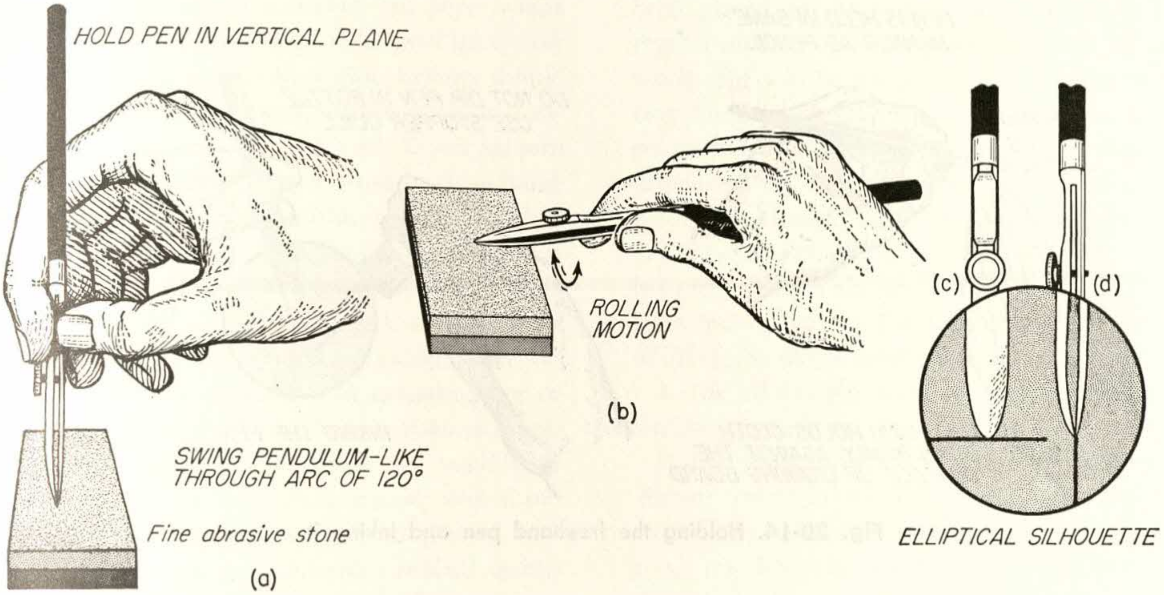


Fig. 20-12. Sharpening the pen.

and (*d*). The pen should be tested at various intervals during the sharpening process to make sure that the ink flows with the proper freedom, that the nibs do not cut into the surface of the paper or cloth, and that even lines of the finest and heaviest desired widths can be obtained. Do not attempt to sharpen the inner surfaces of the blades. Remove any feathered edges by rubbing the pen on a piece of hard leather.

A pen point that is too rounded should be avoided, for the ink will run too readily from the pen. A point that is too steep will prevent the ink from running at all, and an oversharp point will cut into the surface of the tracing paper or cloth.

20-12. Use of the freehand pen. The lettering for notes, specifications, the title block, and all dimensions, including whole numbers and fractions, is inked with a lettering, or freehand, pen. In making an ink tracing of a pencil drawing, penciled horizontal and vertical guide lines should be used to preserve verticality and regularity in the height of the letters and figures. It is not advisable to try to trace the individual characters, but rather to use them as guides in arranging and spacing the lettering on the tracing.

No special pen points need be recommended for freehand ink lettering. Overflexible points should be avoided because they are likely to produce an uneven line, and very stiff points should not be used because they have a tendency to cause the draftsman to "tighten up" and exert excessive pressure. Various types of pens recommended for freehand lettering are shown in Fig. 20-13.

The lettering pen should be held in the hand in the same manner as the pencil, loosely enough and gently enough to give the feeling of perfect freedom for easy manipulation (see Fig. 20-14). A sketchy technique is faulty, because the strokes will present weak, uneven lines of irregular width. A forthright continuous stroke, which can be produced after a little practice, will yield the desired letter line. If the pen is tilted one way or another from its habitual position, the letter strokes will

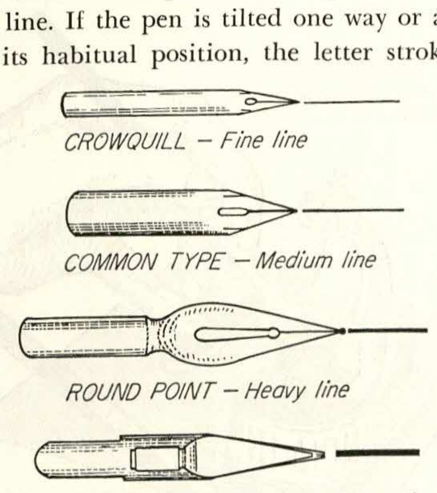


Fig. 20-13. Pens for freehand inking (for lettering, for small fillets and rounds, etc.).

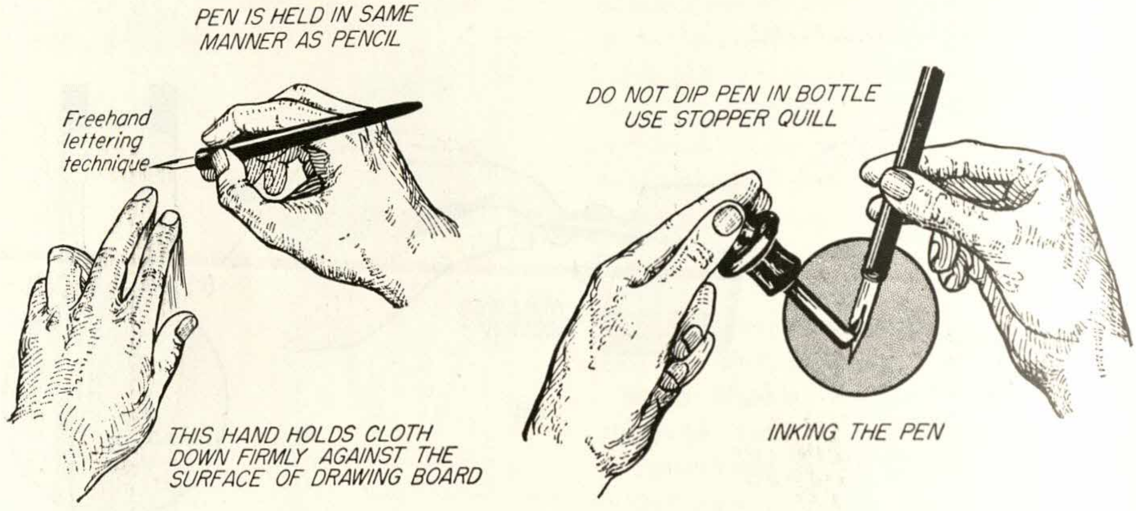

PEN IS HELD IN SAME MANNER AS PENCIL
Freehand lettering technique
THIS HAND HOLDS CLOTH DOWN FIRMLY AGAINST THE SURFACE OF DRAWING BOARD
DO NOT DIP PEN IN BOTTLE USE STOPPER QUILL
INKING THE PEN

Fig. 20-14. Holding the freehand pen and inking it.

vary from those inked while the pen was being held properly.

Dipping the pen in the ink bottle is not a good practice. The pen should be inked by putting the stopper to the slot on the underside, as shown in Fig. 20-14. If ink is permitted to lodge on the point or if too much is applied, the ink will flow too freely and the lettering will start with a blot or the first stroke lines will be unusually heavy. The lettering pen should be cleaned before using and should be wiped frequently when in use. In order to remove caked dried ink, it should be completely cleaned on being put away.

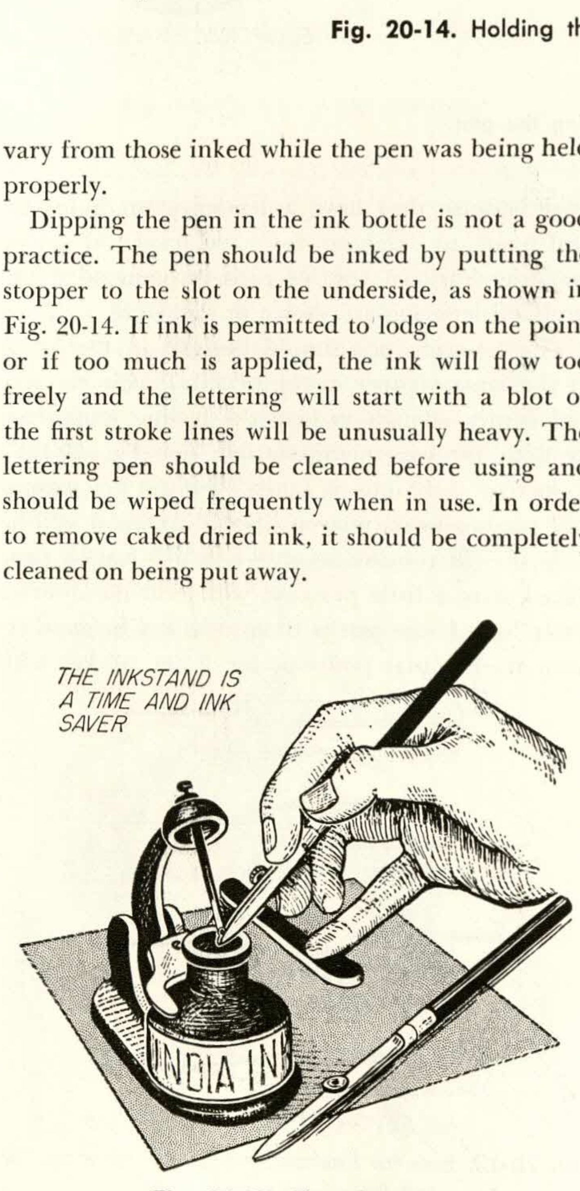

THE INKSTAND IS A TIME AND INK SAVER
INDIA INK

Fig. 20-15. The inkstand.

The pen-filling inkstand shown in Fig. 20-15 saves ink and time, and only one hand is necessary to operate it. It may be used to ink either the ruling pen or the lettering pen. Any $\frac{3}{4}$-oz bottle of drawing ink can be placed under the bottle-holder clamp. A locking device keeps the stopper tight in the neck of the bottle when not in use. The stand is rigid and heavy enough to prevent tipping, and it may be screwed securely to the drawing board or table if desired.

20-13. Erasing. Superfluous pencil lines appearing on an inked drawing may be removed very simply from tracing paper by using a soft rubber or kneaded eraser. Rubbing the paper surface gently will remove the pencil lines without blemishing the ink. The removal of ink from any paper, however, always presents the possibility of so marring the surface that re-inking is impossible. For this reason, it is advisable to use tracing cloth for all ink work, because the treated linen can withstand erasures and other abuses it may be subjected to while being worked on in the drafting room or in the print-making department. The better types of water-repellent wax- and oil-free white tracing cloths need no preparations rubbed on or into their surfaces before starting to ink, and they will stand up under the softer abrasive erasers with no appreciable damage to the working surface. The use of an erasing shield will prevent wrinkling of the paper and the defacing of correct line work. A knife or razor blade may be used to remove a minute error in inking, but never where re-inking is to take place, for the ink will invariably seep through and run at that spot. Erasing should be done by slipping a hard surface, such as a triangle, under the area to be erased. Eraser crumbs should be removed with a soft brush or clean handkerchief, and the erased surface rubbed with a clean finger tip or a bone burnisher especially made for the purpose. An erased area treated in this manner will normally take ink as well as the undisturbed portions of the drawing, and the chances of the ink running and spreading are reduced to a minimum. Pencil lines, carbon or graphite smudges, and hand moisture are usually removed from the finished cloth tracing with a soft rubber eraser. However, a cloth moistened with benzine or carbon tetrachloride rubbed gently over the drawing surface will serve the same purpose.

The electric erasing machine illustrated in Fig. 4-25 is a convenient time- and energy saver. The erasing point is small, and it can be used with the erasing shield. Only the soft-rubber ink erasers should be employed in erasing ink lines. Care must be taken to exert only very gentle pressure in using the machine, since the heat generated by the rubber point turning at high speed will mar or burn through the surface.

20-14. Order of inking. After the light penciled guide lines for notes, specifications, whole numbers, fractions, title information, etc., have been placed on the tracing, it is well to follow a regular order in the inking procedure. By doing so, much time will be saved, and the chances of omitting lines will be minimized. The procedure suggested helps to avoid lines of unequal widths by dispensing with frequent resettings of the pen nibs. Also, little time will be lost waiting for the ink to dry. The natural order for the right-handed person is to move across the paper from left to right and from top to bottom. For most drawings, the order of inking should be as follows:

1. Ink all straight center lines; then follow with circular center lines.
2. Ink visible object lines and cutting-plane lines (heavy lines) in the following order: (*a*) small circles, (*b*) large circles, (*c*) small arcs, (*d*) large arcs, (*e*) irregular curves, (*f*) horizontal lines, (*g*) vertical lines, (*h*) slant lines.
3. Ink hidden object lines (medium lines). Using a medium-weight dash line, start with the small circles, and follow the order suggested in item 2 above.
4. Ink the fine lines in the following order: (*a*) extension lines, (*b*) dimension lines, (*c*) section lining. Ink vertical lines first, horizontal lines next, slant lines last.
5. With the lettering pen, ink (*a*) arrowheads, (*b*) dimension figures, (*c*) specific notes, (*d*) general notes.
6. Ink the border and lettering for the title block, revision strip, and bill of materials.

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Table 1. Trigonometric Functions

Angle	Sine	Cosine	Tan	Cotan	Angle
0°	0.0000	1.0000	0.0000	∞	90°
1°	0.0175	0.9998	0.0175	57.290	89°
2°	0.0349	0.9994	0.0349	28.636	88°
3°	0.0523	0.9986	0.0524	19.081	87°
4°	0.0698	0.9976	0.0699	14.301	86°
5°	0.0872	0.9962	0.0875	11.430	85°
6°	0.1045	0.9945	0.1051	9.5144	84°
7°	0.1219	0.9925	0.1228	8.1443	83°
8°	0.1392	0.9903	0.1405	7.1154	82°
9°	0.1564	0.9877	0.1584	6.3138	81°
10°	0.1736	0.9848	0.1763	5.6713	80°
11°	0.1908	0.9816	0.1944	5.1446	79°
12°	0.2079	0.9781	0.2126	4.7046	78°
13°	0.2250	0.9744	0.2309	4.3315	77°
14°	0.2419	0.9703	0.2493	4.0108	76°
15°	0.2588	0.9659	0.2679	3.7321	75°
16°	0.2756	0.9613	0.2867	3.4874	74°
17°	0.2924	0.9563	0.3057	3.2709	73°
18°	0.3090	0.9511	0.3249	3.0777	72°
19°	0.3256	0.9455	0.3443	2.9042	71°
20°	0.3420	0.9397	0.3640	2.7475	70°
21°	0.3584	0.9336	0.3839	2.6051	69°
22°	0.3746	0.9272	0.4040	2.4751	68°
23°	0.3907	0.9205	0.4245	2.3559	67°
24°	0.4067	0.9135	0.4452	2.2460	66°
25°	0.4226	0.9063	0.4663	2.1445	65°
26°	0.4384	0.8988	0.4877	2.0503	64°
27°	0.4540	0.8910	0.5095	1.9626	63°
28°	0.4695	0.8829	0.5317	1.8807	62°
29°	0.4848	0.8746	0.5543	1.8040	61°
30°	0.5000	0.8660	0.5774	1.7321	60°
31°	0.5150	0.8572	0.6009	1.6643	59°
32°	0.5299	0.8480	0.6249	1.6003	58°
33°	0.5446	0.8387	0.6494	1.5399	57°
34°	0.5592	0.8290	0.6745	1.4826	56°
35°	0.5736	0.8192	0.7002	1.4281	55°
36°	0.5878	0.8090	0.7265	1.3764	54°
37°	0.6018	0.7986	0.7536	1.3270	53°
38°	0.6157	0.7880	0.7813	1.2799	52°
39°	0.6293	0.7771	0.8098	1.2349	51°
40°	0.6428	0.7660	0.8391	1.1918	50°
41°	0.6561	0.7547	0.8693	1.1504	49°
42°	0.6691	0.7431	0.9004	1.1106	48°
43°	0.6820	0.7314	0.9325	1.0724	47°
44°	0.6947	0.7193	0.9657	1.0355	46°
45°	0.7071	0.7071	1.0000	1.0000	45°
Angle	Cosine	Sine	Cotan	Tan	Angle

Table 2. Decimal Equivalents of Inch Fractions

Fraction	Equiv.	Fraction	Equiv.	Fraction	Equiv.	Fraction	Equiv.
1/64	0.015625	17/64	0.265625	33/64	0.515625	49/64	0.765625
1/32	0.03125	9/32	0.28125	17/32	0.53125	25/32	0.78125
3/64	0.046875	19/64	0.296875	35/64	0.546875	51/64	0.796875
1/16	0.0625	5/16	0.3125	9/16	0.5625	13/16	0.8125
5/64	0.078125	21/64	0.328125	37/64	0.578125	53/64	0.828125
3/32	0.09375	11/32	0.34375	19/32	0.59375	27/32	0.84375
7/64	0.109375	23/64	0.359375	39/64	0.609375	55/64	0.859375
1/8	0.1250	3/8	0.3750	5/8	0.6250	7/8	0.8750
9/64	0.140625	25/64	0.390625	41/64	0.640625	57/64	0.890625
5/32	0.15625	13/32	0.40625	21/32	0.65625	29/32	0.90625
11/64	0.171875	27/64	0.421875	43/64	0.671875	59/64	0.921875
3/16	0.1875	7/16	0.4375	11/16	0.6875	15/16	0.9375
13/64	0.203125	29/64	0.453125	45/64	0.703125	61/64	0.953125
7/32	0.21875	15/32	0.46875	23/32	0.71875	31/32	0.96875
15/64	0.234375	31/64	0.484375	47/64	0.734375	63/64	0.984375
1/4	0.2500	1/2	0.5000	3/4	0.7500	1	1.0000

Table 3. Sizes of Numbered and Lettered Drills

Number	Size, in.	Number	Size, in.	Number	Size, in.	Letter	Size, in.
80	0.0135	53	0.0595	26	0.1470	*A*	0.2340
79	0.0145	52	0.0635	25	0.1495	*B*	0.2380
78	0.0160	51	0.0670	24	0.1520	*C*	0.2420
77	0.0180	50	0.0700	23	0.1540	*D*	0.2460
76	0.0200	49	0.0730	22	0.1570	*E*	0.2500
75	0.0210	48	0.0760	21	0.1590	*F*	0.2570
74	0.0225	47	0.0785	20	0.1610	*G*	0.2610
73	0.0240	46	0.0810	19	0.1660	*H*	0.2660
72	0.0250	45	0.0820	18	0.1695	*I*	0.2720
71	0.0260	44	0.0860	17	0.1730	*J*	0.2770
70	0.0280	43	0.0890	16	0.1770	*K*	0.2810
69	0.0292	42	0.0935	15	0.1800	*L*	0.2900
68	0.0310	41	0.0960	14	0.1820	*M*	0.2950
67	0.0320	40	0.0980	13	0.1850	*N*	0.3020
66	0.0330	39	0.0995	12	0.1890	*O*	0.3160
65	0.0350	38	0.1015	11	0.1910	*P*	0.3230
64	0.0360	37	0.1040	10	0.1935	*Q*	0.3320
63	0.0370	36	0.1065	9	0.1960	*R*	0.3390
62	0.0380	35	0.1100	8	0.1990	*S*	0.3480
61	0.0390	34	0.1110	7	0.2010	*T*	0.3580
60	0.0400	33	0.1130	6	0.2040	*U*	0.3680
59	0.0410	32	0.1160	5	0.2055	*V*	0.3770
58	0.0420	31	0.1200	4	0.2090	*W*	0.3860
57	0.0430	30	0.1285	3	0.2130	*X*	0.3970
56	0.0465	29	0.1360	2	0.2210	*Y*	0.4040
55	0.0520	28	0.1405	1	0.2280	*Z*	0.4130
54	0.0550	27	0.1440				

Table 4. ASA-preferred Diameter-Pitch Combinations for Acme and Stub Acme Threads*

Nominal (major) diam., in.	Threads per in.	Nominal (major) diam., in.	Threads per in.	Nominal (major) diam., in.	Threads per in.	Nominal (major) diam., in.	Threads per in.
1/4	16	3/4	6	1 1/2	4	3	2
5/16	14	7/8	6	1 3/4	4	3 1/2	2
3/8	12	1	5	2	4	4	2
7/16	12	1 1/8	5	2 1/4	3	4 1/2	2
1/2	10	1 1/4	5	2 1/2	3	5	2
5/8	8	1 3/8	4	2 3/4	3		

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* ASA B1.5 and B1.8—1952.

Table 5. American Standard Unified and American Thread Series[a]

Threads per Inch for Coarse, Fine, Extra-fine, 8-thread, 12-thread, and 16-thread Series[b]

Tap-drill Sizes for Approximately 75% Depth of Thread (Not American Standard)

Nominal size (basic major diam.)	Coarse thd series UNC and NC[c] in classes 1A, 1B, 2A, 2B, 3A, 3B, 2, 3		Fine thd series UNF and NF[c] in classes 1A, 1B, 2A, 2B, 3A, 3B, 2, 3		Extra-fine thd series UNEF and NEF[d] in classes 2A, 2B, 2, 3		8-thd series 8N[c] in classes 2A, 2B, 2, 3		12-thd series 12 UN and 12N[d] in classes 2A, 2B, 2, 3		16-thd series 16 UN and 16N[d] in classes 2A, 2B, 2, 3	
	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill
0(0.060)	....	.....	80	3/64								
1(0.073)	64	No. 53	72	No. 53								
2(0.086)	56	No. 50	64	No. 50								
3(0.099)	48	No. 47	56	No. 45								
4(0.112)	**40**	No. 43	48	No. 42								
5(0.125)	40	No. 38	44	No. 37								
6(0.138)	**32**	No. 36	40	No. 33								
8(0.164)	**32**	No. 29	36	No. 29								
10(0.190)	**24**	No. 25	**32**	No. 21								
12(0.216)	24	No. 16	28	No. 14	32	No. 13						
1/4	**20**	No. 7	**28**	No. 3	32	7/32						
5/16	**18**	Let. F	**24**	Let. I	32	9/32						
3/8	**16**	5/16	**24**	Let. Q	32	11/32						
7/16	**14**	Let. U	**20**	25/64	**28**	13/32						
1/2	**13**	27/64	**20**	29/64	**28**	15/32	..	...	**12**	27/64		
9/16	**12**	31/64	**18**	33/64	24	33/64	..	...	**12**	31/64		
5/8	**11**	17/32	**18**	37/64	24	37/64	..	...	12	35/64		
11/16	....	.....	..	.....	24	41/64	..	...	12	39/64		
3/4	**10**	21/32	**16**	11/16	**20**	45/64	..	...	12	43/64	**16**	11/16
13/16	....	.....	..	.....	**20**	49/64	..	...	12	47/64	**16**	3/4
7/8	**9**	49/64	**14**	13/16	**20**	53/64	..	...	12	51/64	**16**	13/16
15/16	....	.....	..	.....	**20**	57/64	..	...	**12**	55/64	**16**	7/8
1	....	.....	14	15/16	..	.....	8	7/8				
1	**8**	7/8	**12**	59/64	**20**	61/64	..	...	**12**	59/64	**16**	15/16
1 1/16	....	.....	..	.....	18	1	..	...	**12**	63/64	**16**	1
1 1/8	**7**	63/64	**12**	1 3/64	18	1 5/64	8	1	**12**	1 3/64	**16**	1 1/16
1 3/16	....	.....	..	.....	18	1 9/64	..	...	**12**	1 7/64	**16**	1 1/8
1 1/4	**7**	1 7/64	**12**	1 11/64	18	1 3/16	8	1 1/8	**12**	1 11/64	**16**	1 3/16
1 5/16	....	.....	..	.....	18	1 17/64	..	...	**12**	1 15/64	**16**	1 1/4
1 3/8	**6**	1 7/32	**12**	1 19/64	18	1 5/16	8	1 1/4	**12**	1 19/64	**16**	1 5/16
1 7/16	....	.....	..	.....	18	1 3/8	..	...	**12**	1 23/64	**16**	1 3/8
1 1/2	**6**	1 11/32	**12**	1 27/64	18	1 7/16	8	3/8	**12**	1 27/64	**16**	1 7/16
1 9/16	....	.....	..	.....	18	1 1/2	..	...	..	.....	16	1 1/2
1 5/8	....	.....	..	.....	18	1 9/16	8	1 1/2	12	1 35/64	16	1 9/16
1 11/16	....	.....	..	.....	18	1 5/8	..	...	..	.....	16	1 5/8
1 3/4	**5**	1 9/16	..	.....	**16**	1 11/16	8[e]	1 5/8	**12**	1 43/64	**16**	1 11/16
1 13/16	....	.....	..	.....	..	.....	..	...	..	.....	16	1 3/4
1 7/8	....	.....	..	.....	..	.....	8	1 3/4	12	1 51/64	16	1 13/16
1 15/16	....	.....	..	.....	..	.....	..	...	..	.....	16	1 7/8

Table 5. American Standard Unified and American Thread Series[a]—(*Continued*)

Nominal size (basic major diam.)	Coarse thd series UNC and NC[c] in classes 1A, 1B, 2A, 2B, 3A, 3B, 2, 3		Fine thd series UNF and NF[c] in classes 1A, 1B, 2A, 2B, 3A, 3B, 2, 3		Extra-fine thd series UNEF and NEF[d] in classes 2A, 2B, 2, 3		8-thd series 8N[c] in classes 2A, 2B, 2, 3		12-thd series 12 UN and 12N[d] in classes 2A, 2B, 2, 3		16-thd series 16 UN and 16N[d] in classes 2A, 2B, 2, 3	
	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill	Thds per in.	Tap drill
2	**4 1/2**	1 25/32	..	.....	**16**	1 15/16	8[e]	1 7/8	**12**	1 59/64	**16**	1 15/16
2 1/16	....	.....	..	.....	..	.....	..	...	..	.....	16	2
2 1/8	....	.....	..	.....	..	.....	8	2	12	2 3/64	16	2 1/16
2 3/16	....	.....	..	.....	..	.....	..	...	..	.....	16	2 1/8
2 1/4	**4 1/2**	2 1/32	..	.....	..	.....	8[e]	2 1/8	**12**	2 11/64	**16**	2 3/16
2 5/16	....	.....	..	.....	..	.....	..	...	..	.....	16	2 1/4
2 3/8	....	.....	..	.....	..	.....	..	...	12	2 19/64	16	2 5/16
2 7/16	....	.....	..	.....	..	.....	..	...	..	.....	16	2 3/8
2 1/2	**4**	2 1/4	..	.....	..	.....	8[e]	2 3/8	**12**	2 27/64	**16**	2 7/16
2 5/8	....	.....	..	.....	..	.....	..	...	12	2 35/64	16	2 9/16
2 3/4	**4**	2 1/2	..	.....	..	.....	8[e]	2 5/8	**12**	2 43/64	**16**	2 11/16
2 7/8	....	.....	..	.....	..	.....	..	...	12	2 51/64	16	2 13/16
3	**4**	2 3/4	..	.....	..	.....	8[e]	2 7/8	**12**	2 59/64	**16**	2 15/16
3 1/8	....	.....	..	.....	..	.....	..	...	12	3 3/64	16	3 1/16
3 1/4	**4**	3	..	.....	..	.....	8[e]	3 1/8	**12**	3 11/64	**16**	3 3/16
3 3/8	....	.....	..	.....	..	.....	..	...	12	3 19/64	16	3 5/16
3 1/2	**4**	3 1/4	..	.....	..	.....	8[e]	3 3/8	**12**	3 27/64	**16**	3 7/16
3 5/8	....	.....	..	.....	..	.....	..	...	12	3 35/64	16	3 9/16
3 3/4	**4**	3 1/2	..	.....	..	.....	8[e]	3 5/8	**12**	3 43/64	**16**	3 11/16
3 7/8	....	.....	..	.....	..	.....	..	...	12	3 51/64	16	3 13/16
4	**4**	3 3/4	..	.....	..	.....	8[e]	3 7/8	**12**	3 59/64	**16**	3 15/16
4 1/4	....	.....	..	.....	..	.....	8[e]	4 1/8	**12**	4 11/64	**16**	4 3/16
4 1/2	....	.....	..	.....	..	.....	8[e]	4 3/8	**12**	4 27/64	**16**	4 7/16
4 3/4	....	.....	..	.....	..	.....	8[e]	4 5/8	**12**	4 43/64	**16**	4 11/16
5	....	.....	..	.....	..	.....	8[e]	4 7/8	**12**	4 59/64	**16**	4 15/16
5 1/4	....	.....	..	.....	..	.....	8	5 1/8	**12**	5 11/64	**16**	5 3/16
5 1/2	....	.....	..	.....	..	.....	8	5 3/8	**12**	5 27/64	**16**	5 7/16
5 3/4	....	.....	..	.....	..	.....	8	5 5/8	**12**	5 43/64	**16**	5 11/16
6	....	.....	..	.....	..	.....	8	5 7/8	**12**	5 59/64	**16**	5 15/16

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[a] ASA B1.1—1949.

[b] Dimensions are in inches. Boldface type indicates unified threads.

[c] Limits of size for classes are based on a length of engagement equal to the nominal diameter.

[d] Limits of size for classes are based on a length of engagement equal to nine times the pitch.

[e] These sizes with specified limits of size based on a length of engagement of 9 threads in classes 2A and 2B are designated UN.

NOTE: If a thread is in both the 8-, 12-, or 16-thread series and the coarse, fine, or extra-fine thread series, the symbols and tolerances of the latter series apply.

Table 6. American Standard Square and Hexagon Bolts and Hexagon Cap Screw*

Nominal size (basic major diameter)	Regular bolts			Heavy bolts		
	Width across flats W, sq† and hex	Height H		Width across flats W	Height H	
		Unfin sq and hex	Semifin hex and hex screw‡		Unfin hex	Semifin hex and hex screw
1/4	3/8(sq), 7/16(hex)	11/64	5/32			
5/16	1/2	7/32	13/64			
3/8	9/16	1/4	15/64			
7/16	5/8	19/64	9/32			
1/2	3/4	11/32	5/16	7/8	7/16	13/32
9/16	13/16	25/64	23/64	15/16	15/32	7/16
5/8	15/16	27/64	25/64	1 1/16	17/32	1/2
3/4	1 1/8	1/2	15/32	1 1/4	5/8	19/32
7/8	1 5/16	37/64	35/64	1 7/16	23/32	11/16
1	1 1/2	43/64	39/64	1 5/8	13/16	3/4
1 1/8	1 11/16	3/4	11/16	1 13/16	29/32	27/32
1 1/4	1 7/8	27/32	25/32	2	1	15/16
1 3/8	2 1/16	29/32	27/32	2 3/16	1 3/32	1 1/32
1 1/2	2 1/4	1	15/16	2 3/8	1 3/16	1 1/8
1 5/8	2 7/16	1 1/16	1	2 9/16	1 9/32	1 7/32
1 3/4	2 5/8	1 5/32	1 3/32	2 3/4	1 3/8	1 5/16
1 7/8	2 13/16	1 7/32	1 5/32	2 15/16	1 15/32	1 13/32
2	3	1 11/32	1 7/32	3 1/8	1 9/16	1 7/16
2 1/4	3 3/8	1 1/2	1 3/8	3 1/2	1 3/4	1 5/8
2 1/2	3 3/4	1 21/32	1 17/32	3 7/8	1 15/16	1 13/16
2 3/4	4 1/8	1 13/16	1 11/16	4 1/4	2 1/8	2
3	4 1/2	2	1 7/8	4 5/8	2 5/16	2 3/16
3 1/4	4 7/8	2 3/16	2			
3 1/2	5 1/4	2 5/16	2 1/8			
3 3/4	5 5/8	2 1/2	2 5/16			
4	6	2 11/16	2 1/2			

All dimensions in inches.

* ASA B18.2—1952.

† Square bolts in (nominal) size from 1/4 to 1 1/2 only.

‡ Hexagon-head cap screw, automotive hexagon-head bolt, and close-tolerance regular bolt; lengths from 1/4 to 3 in. only.

NOTE. Bolt lengths are not standardized. For diameters 1/4 to 1/2 in., increments are 1/4 in. beyond 3/4-in. length. For diameters 1/2 to 1 in., increments are 1/2 in. beyond 6-in. lengths. For bolts larger than 1 in. in diameter the lengths increase by 2 to 4 in. beyond 12-in. lengths.

Threads are coarse series, class 2A except with hexagon screw which is coarse, fine, or 8-pitch series, class 2A.

Minimum thread length: $2D + \frac{1}{4}$ in. for bolts 6 in. or less in length.
$2D + \frac{1}{2}$ in. for bolts over 6 in. in length.
Bolts too short for formula, thread entire length.

Table 7. American Standard Square and Hexagon Nuts*

Nominal size (basic major diameter)	Regular nuts†						Heavy nuts†						
	Width across flats *W*, sq and hex	Thickness *T*					Width across flats *W*, sq and hex	Thickness *T*				Slot	
		Unfin sq and hex	Unfin hex jam	Semi-fin hex and hex slotted‡	Semi-fin hex jam	Semi-fin hex thick, thick slotted,‡ and castle		Unfin sq and hex	Unfin hex jam	Semi-fin hex and hex slotted	Semi-fin hex jam	Width	Depth
1/4	7/16	15/64	11/64	7/32	5/32	9/32	1/2	1/4	3/16	15/64	11/64	5/64	3/32
5/16	1/2	9/32	13/64	17/64	3/16	21/64	9/16	5/16	7/32	19/64	13/64	3/32	3/32
3/8	9/16	11/32	15/64	21/64	7/32	13/32	11/16	3/8	1/4	23/64	15/64	1/8	1/8
7/16	11/16	25/64	17/64	3/8	1/4	29/64	3/4	7/16	9/32	27/64	17/64	1/8	5/32
1/2	3/4	29/64	21/64	7/16	5/16	9/16	7/8	1/2	5/16	31/64	19/64	5/32	5/32
9/16	7/8	1/2	21/64	31/64	5/16	39/64	15/16	9/16	11/32	35/64	21/64	5/32	3/16
5/8	15/16	9/16	25/64	35/64	3/8	23/32	1 1/16	5/8	3/8	39/64	23/64	3/16	7/32
3/4	1 1/8	21/32	7/16	41/64	27/64	13/16	1 1/4	3/4	7/16	47/64	27/64	3/16	1/4
7/8	1 5/16	49/64	1/2	3/4	31/64	29/32	1 7/16	7/8	1/2	55/64	31/64	3/16	1/4
1	1 1/2	7/8	9/16	55/64	35/64	1	1 5/8	1	9/16	63/64	35/64	1/4	9/32
1 1/8	1 11/16	1	5/8	31/32	39/64	1 5/32	1 13/16	1 1/8	5/8	1 7/64	39/64	1/4	11/32
1 1/4	1 7/8	1 3/32	3/4	1 1/16	23/32	1 1/4	2	1 1/4	3/4	1 7/32	23/32	5/16	3/8
1 3/8	2 1/16	1 13/64	13/16	1 11/64	25/32	1 3/8	2 3/16	1 3/8	13/16	1 11/32	25/32	5/16	3/8
1 1/2	2 1/4	1 5/16	7/8	1 9/32	27/32	1 1/2	2 3/8	1 1/2	7/8	1 15/32	27/32	3/8	7/16
1 5/8	2 7/16	.....	....	1 25/64	29/32	.....	2 9/16	1 5/8	15/16	1 19/32	29/32	3/8	7/16
1 3/4	2 5/8	.....	....	1 1/2	31/32	.....	2 3/4	1 3/4	1	1 23/32	31/32	7/16	1/2
1 7/8	2 13/16	.....	....	1 39/64	1 1/32	.....	2 15/16	1 7/8	1 1/16	1 27/32	1 1/32	7/16	9/16
2	3	.....	....	1 23/32	1 3/32	.....	3 1/8	2	1 1/8	1 31/32	1 3/32	7/16	9/16
2 1/4	3 3/8	.....	....	1 59/64	1 13/64	.....	3 1/2	2 1/4	1 1/4	2 13/64	1 13/64	7/16	9/16
2 1/2	3 3/4	.....	....	2 9/64	1 29/64	.....	3 7/8	2 1/2	1 1/2	2 29/64	1 29/64	9/16	11/16
2 3/4	2 1/8	.....	....	2 23/64	1 37/64	.....	4 1/4	2 3/4	1 5/8	2 45/64	1 37/64	9/16	11/16
3	4 1/2	.....	....	2 37/64	1 45/64	.....	4 5/8	3	1 3/4	2 61/64	1 45/64	5/8	3/4
3 1/4	.....	.....	....	.....	.....	.....	5	3 1/4	1 7/8	3 3/16	1 13/16	5/8	3/4
3 1/2	.....	.....	....	.....	.....	.....	5 3/8	3 1/2	2	3 7/16	1 15/16	5/8	3/4
3 3/4	.....	.....	....	.....	.....	.....	5 3/4	3 3/4	2 1/8	3 11/16	2 1/16	5/8	3/4
4	.....	.....	....	.....	.....	.....	6 1/8	4	2 1/4	3 15/16	2 3/16	5/8	3/4

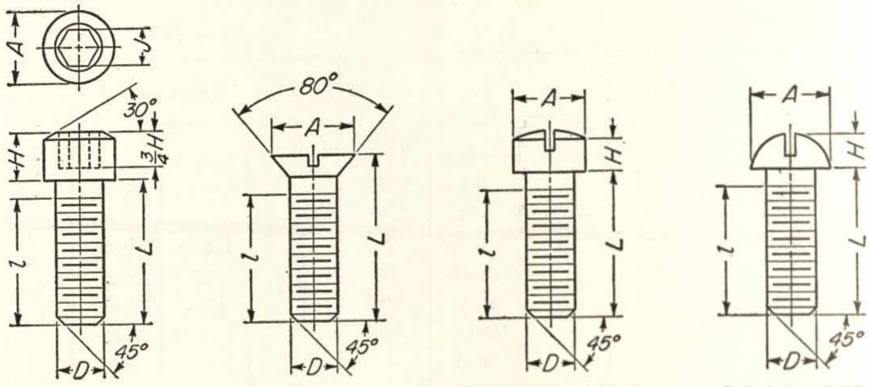
All dimensions in inches.

* ASA B18.2—1952.

† Thread for unfinished nuts: coarse series, class 2B; for semifinished nuts: coarse, fine, or 8-pitch series, class 2B.

‡ Slot dimensions for regular slotted nuts are same as for heavy slotted nuts.

Table 8. American Standard Cap Screws, Socket and Slotted Heads*



SOCKET HEAD FLAT HEAD FILLISTER HEAD ROUND HEAD

Nominal diameter	Socket head†			Flat head‡	Fillister head		Round head‡	
	A	H	J	A	A	H	A	H
2	0.140	0.086	1/16					
3	0.161	0.099	5/64					
4	0.183	0.112	5/64					
5	0.205	0.125	3/32					
6	0.226	0.138	3/32					
8	0.270	0.164	1/8					
10	5/16	0.190	5/32					
12	11/32	0.216	5/32					
1/4	3/8	1/4	3/16	1/2	3/8	11/64	7/16	3/16
5/16	7/16	5/16	7/32	5/8	7/16	13/64	9/16	15/64
3/8	9/16	3/8	5/16	3/4	9/16	1/4	5/8	17/64
7/16	5/8	7/16	5/16	13/16	5/8	19/64	3/4	5/16
1/2	3/4	1/2	3/8	7/8	3/4	21/64	13/16	11/32
9/16	13/16	9/16	3/8	1	13/16	3/8	15/16	13/32
5/8	7/8	5/8	1/2	1 1/8	7/8	27/64	1	7/16
3/4	1	3/4	9/16	1 3/8	1	1/2	1 1/4	17/32
7/8	1 1/8	7/8	9/16	1 5/8	1 1/8	19/32		
1	1 5/16	1	5/8	1 7/8	1 5/16	21/32		
1 1/8	1 1/2	1 1/8	3/4					
1 1/4	1 3/4	1 1/4	3/4					
1 3/8	1 7/8	1 3/8	3/4					
1 1/2	2	1 1/2	1					

All dimensions in inches.

Slot proportions vary with size of screw; see text for empirical formulas.

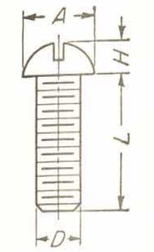
* ASA B18.3—1947 and ASA B18.6—1947.

† Body length increments: For screw lengths 1/4 to 1 in. = 1/8 in.
For screw lengths 1 to 4 in. = 1/4 in.
For screw lengths 4 to 6 in. = 1/2 in.
Thread length, l: For coarse thread: $2D + \frac{1}{2}$ in.
For fine thread: $1\frac{1}{2}D + \frac{1}{2}$ in.

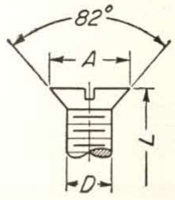
‡ Thread either coarse or fine, class 3.
Thread length, l: $2D + \frac{1}{4}$ in.
Body length increments may be taken the same as for socket-head screws.

Table 9. American Standard Machine Screws*

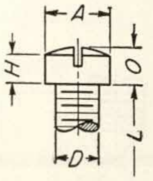
Heads May Be Slotted or Recessed†



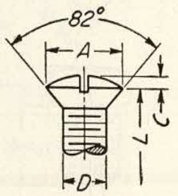
ROUND HEAD



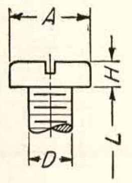
FLAT HEAD



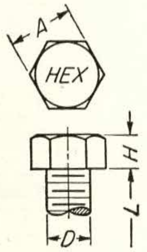
FILLISTER HEAD



OVAL HEAD



PAN HEAD



HEX HEAD

Nominal diameter	Round head		Flat head	Fillister head			Oval head		Pan head		Hexagon head	
	A	*H*	*A*	*A*	*H*	*O*	*A*	*C*	*A*	*H*	*A*	*H*
0	0.113	0.053	0.119	0.096	0.045	0.059	0.119	0.021				
1	0.138	0.061	0.146	0.118	0.053	0.071	0.146	0.025				
2	0.162	0.069	0.172	0.140	0.062	0.083	0.172	0.029	0.167	0.053	0.125	0.050
3	0.187	0.078	0.199	0.161	0.070	0.095	0.199	0.033	0.193	0.060	0.187	0.055
4	0.211	0.086	0.225	0.183	0.079	0.107	0.225	0.037	0.219	0.068	0.187	0.060
5	0.236	0.095	0.252	0.205	0.088	0.120	0.252	0.041	0.245	0.075	0.187	0.070
6	0.260	0.103	0.279	0.226	0.096	0.132	0.279	0.045	0.270	0.082	0.250	0.080
8	0.309	0.120	0.332	0.270	0.113	0.156	0.332	0.052	0.322	0.096	0.250	0.110
10	0.359	0.137	0.385	0.313	0.130	0.180	0.385	0.060	0.373	0.110	0.312	0.120
12	0.408	0.153	0.438	0.357	0.148	0.205	0.438	0.068	0.425	0.125	0.312	0.155
¼	0.472	0.175	0.507	0.414	0.170	0.237	0.507	0.079	0.492	0.144	0.375	0.190
5⁄16	0.590	0.216	0.635	0.518	0.211	0.295	0.635	0.099	0.615	0.178	0.500	0.230
⅜	0.708	0.256	0.762	0.622	0.253	0.355	0.762	0.117	0.740	0.212	0.562	0.295
7⁄16	0.750	0.328	0.812	0.625	0.265	0.368	0.812	0.122				
½	0.813	0.355	0.875	0.750	0.297	0.412	0.875	0.131				
9⁄16	0.938	0.410	1.000	0.812	0.336	0.466	1.000	0.150				
⅝	1.000	0.438	1.125	0.875	0.375	0.521	1.125	0.169				
¾	1.250	0.547	1.375	1.000	0.441	0.612	1.375	0.206				

Dimensions given are maximum values, all in inches.

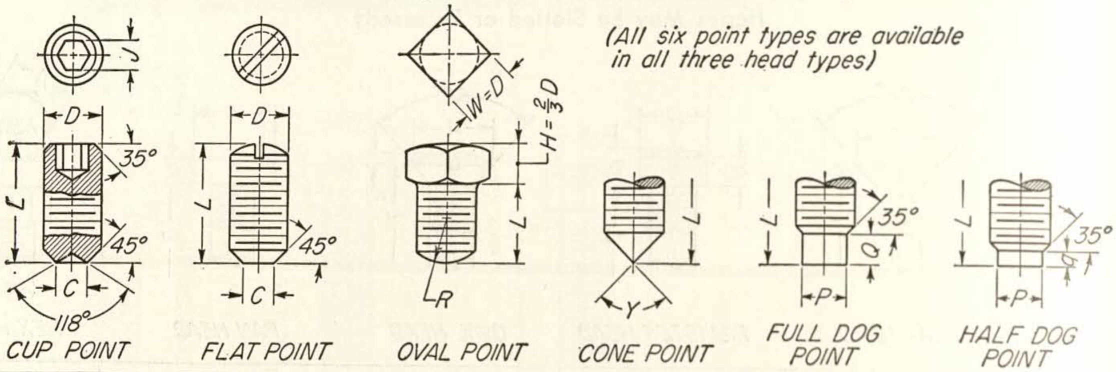
* ASA B18.6—1947.

† Except hexagon head which is plain or may be slotted if so specified. Slot and recess proportions vary with size of fastener; see text for empirical formulas.

Thread length: For screws 2 in. long or less, thread entire length.
For screws 2 in. long or more, thread length (*l*) = 1¾ in.

Threads are coarse or fine series, class 2.

Table 10. American Standard Hexagon Sockets, Slotted Headless, and Square-head Setscrews*



Diameter *D*	Cup and flat-point diameter *C*	Oval-point radius *R*	Cone-point angle *Y*: 118° for these lengths and shorter	Cone-point angle *Y*: 90° for these lengths and longer	Full and half dog points: Diameter *P*	Full and half dog points: Length: Full *Q*	Full and half dog points: Length: Half *q*	Socket width *J*
5	1/16	3/32	1/8	3/16	0.083	0.06	0.03	1/16
6	0.069	7/64	1/8	3/16	0.092	0.07	0.03	1/16
8	5/64	1/8	3/16	1/4	0.109	0.08	0.04	5/64
10	3/32	9/64	3/16	1/4	0.127	0.09	0.04	3/32
12	7/64	5/32	3/16	1/4	0.144	0.11	0.06	3/32
1/4	1/8	3/16	1/4	5/16	5/32	1/8	1/16	1/8
5/16	11/64	15/64	5/16	3/8	13/64	5/32	5/64	5/32
3/8	13/64	9/32	3/8	7/16	1/4	3/16	3/32	3/16
7/16	15/64	21/64	7/16	1/2	19/64	7/32	7/64	7/32
1/2	9/32	3/8	1/2	9/16	11/32	1/4	1/8	1/4
9/16	5/16	27/64	9/16	5/8	25/64	9/32	9/64	1/4
5/8	23/64	15/32	5/8	3/4	15/32	5/16	5/32	5/16
3/4	7/16	9/16	3/4	7/8	9/16	3/8	3/16	3/8
7/8	33/64	21/32	7/8	1	21/32	7/16	7/32	1/2
1	19/32	3/4	1	1 1/8	3/4	1/2	1/4	9/16
1 1/8	43/64	27/32	1 1/8	1 1/4	27/32	9/16	9/32	9/16
1 1/4	3/4	15/16	1 1/4	1 1/2	15/16	5/8	5/16	5/8
1 3/8	53/64	1 1/32	1 3/8	1 5/8	1 1/32	11/16	11/32	5/8
1 1/2	29/32	1 1/8	1 1/2	1 3/4	1 1/8	3/4	3/8	3/4
1 3/4	1 1/16	1 5/16	1 3/4	2	1 5/16	7/8	7/16	1
2	1 7/32	1 1/2	2	2 1/4	1 1/2	1	1/2	1

All dimensions are in inches.

* ASA B18.3—1947, ASA B18.6—1947, and ASA B18—1951.

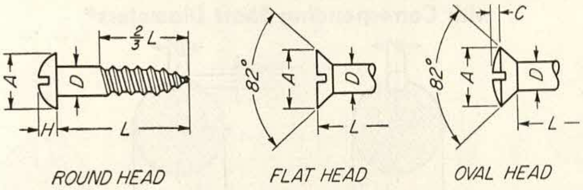
Length increments: For screw lengths 1/4 to 5/8 in. = 1/16 in.
For screw lengths 5/8 to 1 in. = 1/8 in.
For screw lengths 1 to 4 in. = 1/4 in.
For screw lengths 4 to 6 in. = 1/2 in.

Threads are coarse or fine series, classes 2 or 2A.

Slotted headless screws standardized in sizes No. 5 to 3/4 in. only. Slot proportions vary with diameter; see text for empirical formulas.

Square-head setscrews are standardized in sizes No. 10 to 1 1/2 in. only.

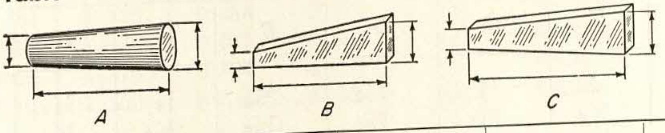
Table 11. American Standard Wood Screws*



Nominal size	Basic diameter of screw D	No. of threads per in.†	Slot width‡ (all heads)	Round head		Flat head	Oval head	
				A	H	A	A	C
0	0.060	32	0.023	0.113	0.053	0.119	0.119	0.021
1	0.073	28	0.026	0.138	0.061	0.146	0.146	0.025
2	0.086	26	0.031	0.162	0.069	0.172	0.172	0.029
3	0.099	24	0.035	0.187	0.078	0.199	0.199	0.033
4	0.112	22	0.039	0.211	0.086	0.225	0.225	0.037
5	0.125	20	0.043	0.236	0.095	0.252	0.252	0.041
6	0.138	18	0.048	0.260	0.103	0.279	0.279	0.045
7	0.151	16	0.048	0.285	0.111	0.305	0.305	0.049
8	0.164	15	0.054	0.309	0.120	0.332	0.332	0.052
9	0.177	14	0.054	0.334	0.128	0.358	0.358	0.056
10	0.190	13	0.060	0.359	0.137	0.385	0.385	0.060
12	0.216	11	0.067	0.408	0.153	0.438	0.438	0.068
14	0.242	10	0.075	0.457	0.170	0.491	0.491	0.076
16	0.268	9	0.075	0.506	0.187	0.544	0.544	0.084
18	0.294	8	0.084	0.555	0.204	0.597	0.597	0.092
20	0.320	8	0.084	0.604	0.220	0.650	0.650	0.100
24	0.372	7	0.094	0.702	0.254	0.756	0.756	0.116

Dimensions given are maximum values, all in inches. Heads may be slotted or recessed as specified.
* ASA B18.6—1947. † Thread length = ⅔L. ‡ Slots vary with type and size of screw; draw to look well.

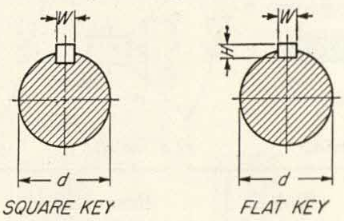
Table 12. Dimensions of Taper Pins—Taper ¼″ per Foot



Size No.	Diameter, large end	Drill size for reamer	Max length	Size No.	Diameter, large end	Drill size for reamer	Max length
000000	0.072	53	⅝	5	0.289	¼	2¼
00000	0.092	47	⅝	6	0.341	9/32	3¼
0000	0.108	42	¾	7	0.409	11/32	3¾
000	0.125	37	¾	8	0.492	13/32	4½
00	0.147	31	1	9	0.591	31/64	5¼
0	0.156	28	1	10	0.706	19/32	6
1	0.172	25	1¼	11	0.857	23/32	7¼
2	0.193	19	1½	12	1.013	55/64	8¾
3	0.219	12	1¾	13	1.233	1 1/64	10¾
4	0.250	3	2				

All dimensions in inches.

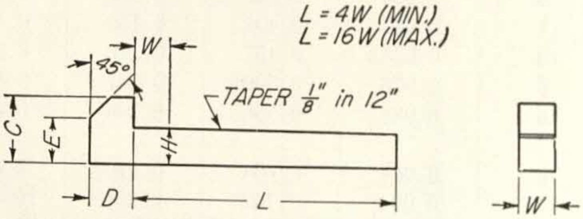
Table 13. ASA-approved Widths and Heights of Standard Square and Flat Keys with Corresponding Shaft Diameters*



Shaft diameter *d* (inclusive)	Square-stock keys *W*	Flat-stock keys, *W* × *H*	Shaft diameter *d* (inclusive)	Square-stock keys *W*	Flat-stock keys, *W* × *H*
1/2 - 9/16	1/8	1/8 × 3/32	2 5/16-2 3/4	5/8	5/8 × 7/16
5/8 - 7/8	3/16	3/16 × 1/8	2 7/8 -3 1/4	3/4	3/4 × 1/2
15/16-1 1/4	1/4	1/4 × 3/16	3 3/8 -3 3/4	7/8	7/8 × 5/8
1 5/16-1 3/8	5/16	5/16 × 1/4	3 7/8 -4 1/2	1	1 × 3/4
1 7/16-1 3/4	3/8	3/8 × 1/4	4 3/4 -5 1/2	1 1/4	1 1/4 × 7/8
1 13/16-2 1/4	1/2	1/2 × 3/8	5 3/4-6	1 1/2	1 1/2 × 1

Dimensions in inches.
* ASA B17.1—1943.

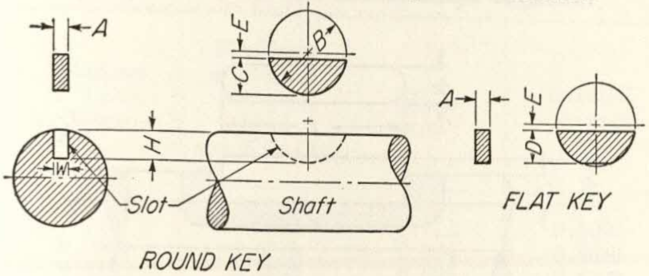
Table 14. ASA-approved Dimensions of Standard Gib-head Keys, Square and Flat*



Diameters of shafts	Square type					Flat type				
	Key		Gib head			Key		Gib head		
	W	*H*	*C*	*D*	*E*	*W*	*H*	*C*	*D*	*E*
1/2 - 9/16	1/8	1/8	1/4	7/32	5/32	1/8	3/32	3/16	1/8	1/8
5/8 - 7/8	3/16	3/16	5/16	9/32	7/32	3/16	1/8	1/4	3/16	5/32
15/16-1 1/4	1/4	1/4	7/16	11/32	11/32	1/4	3/16	5/16	1/4	3/16
1 5/16-1 3/8	5/16	5/16	9/16	13/32	13/32	5/16	1/4	3/8	5/16	1/4
1 7/16-1 3/4	3/8	3/8	11/16	15/32	15/32	3/8	1/4	7/16	3/8	5/16
1 13/16-2 1/4	1/2	1/2	7/8	19/32	5/8	1/2	3/8	5/8	1/2	7/16
2 5/16-2 3/4	5/8	5/8	1 1/16	23/32	3/4	5/8	7/16	3/4	5/8	1/2
2 7/8 -3 1/4	3/4	3/4	1 1/4	7/8	7/8	3/4	1/2	7/8	3/4	5/8
3 3/8 -3 3/4	7/8	7/8	1 1/2	1	1	7/8	5/8	1 1/16	7/8	3/4
3 7/8 -4 1/2	1	1	1 3/4	1 3/16	1 3/16	1	3/4	1 1/4	1	1 3/16
4 3/4 -5 1/2	1 1/4	1 1/4	2	1 7/16	1 7/16	1 1/4	7/8	1 1/2	1 1/4	1
5 3/4 -6	1 1/2	1 1/2	2 1/2	1 3/4	1 3/4	1 1/2	1	1 3/4	1 1/2	1 1/4

Dimensions in inches.
* ASA B17.1—1943.

Table 15. Woodruff Key and Key-slot Dimensions



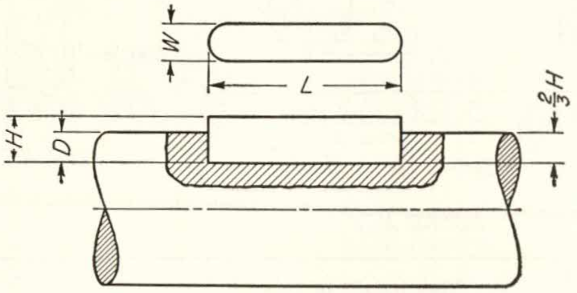
Key No.*	Nominal size $A \times B$	Max width of key A	Max diam of key B	Max height of key C	Max height of key D	Distance below center E	Key slot: Max width, W	Key slot: Min width, W	Key slot: Max depth, H	Key slot: Min depth, H
204	1/16 × 1/2	0.0635	0.500	0.203	0.194	3/64	0.0630	0.0615	0.1718	0.1668
304	3/32 × 1/2	0.0948	0.500	0.203	0.194	3/64	0.0943	0.0928	0.1561	0.1511
305	3/32 × 5/8	0.0948	0.625	0.250	0.240	1/16	0.0943	0.0928	0.2031	0.1981
404	1/8 × 1/2	0.1260	0.500	0.203	0.194	3/64	0.1255	0.1240	0.1405	0.1355
405	1/8 × 5/8	0.1260	0.625	0.250	0.240	1/16	0.1255	0.1240	0.1875	0.1825
406	1/8 × 3/4	0.1260	0.750	0.313	0.303	1/16	0.1255	0.1240	0.2505	0.2455
505	5/32 × 5/8	0.1573	0.625	0.250	0.240	1/16	0.1568	0.1553	0.1719	0.1669
506	5/32 × 3/4	0.1573	0.750	0.313	0.303	1/16	0.1568	0.1553	0.2349	0.2299
507	5/32 × 7/8	0.1573	0.875	0.375	0.365	1/16	0.1568	0.1553	0.2969	0.2919
606	3/16 × 3/4	0.1885	0.750	0.313	0.303	1/16	0.1880	0.1863	0.2193	0.2143
607	3/16 × 7/8	0.1885	0.875	0.375	0.365	1/16	0.1880	0.1863	0.2813	0.2763
608	3/16 × 1	0.1885	1.000	0.438	0.428	1/16	0.1880	0.1863	0.3443	0.3393
609	3/16 × 1 1/8	0.1885	1.125	0.484	0.475	5/64	0.1880	0.1863	0.3903	0.3853
807	1/4 × 7/8	0.2510	0.875	0.375	0.365	1/16	0.2505	0.2487	0.2500	0.2450
808	1/4 × 1	0.2510	1.000	0.438	0.428	1/16	0.2505	0.2487	0.3130	0.3080
809	1/4 × 1 1/8	0.2510	1.125	0.484	0.475	5/64	0.2505	0.2487	0.3590	0.3540
810	1/4 × 1 1/4	0.2510	1.250	0.547	0.537	5/64	0.2505	0.2487	0.4220	0.4170
811	1/4 × 1 3/8	0.2510	1.375	0.594	0.584	3/32	0.2505	0.2487	0.4690	0.4640
812	1/4 × 1 1/2	0.2510	1.500	0.641	0.631	7/64	0.2505	0.2487	0.5160	0.5110
1008	5/16 × 1	0.3135	1.000	0.438	0.428	1/16	0.3130	0.3111	0.2818	0.2768
1009	5/16 × 1 1/8	0.3135	1.125	0.484	0.475	5/64	0.3130	0.3111	0.3278	0.3228
1010	5/16 × 1 1/4	0.3135	1.250	0.547	0.537	5/64	0.3130	0.3111	0.3908	0.3858
1011	5/16 × 1 3/8	0.3135	1.375	0.594	0.584	3/32	0.3130	0.3111	0.4378	0.4328
1012	5/16 × 1 1/2	0.3135	1.500	0.641	0.631	7/64	0.3130	0.3111	0.4848	0.4798
1210	3/8 × 1 1/4	0.3760	1.250	0.547	0.537	5/64	0.3755	0.3735	0.3595	0.3545
1211	3/8 × 1 3/8	0.3760	1.375	0.594	0.584	3/32	0.3755	0.3735	0.4060	0.4015
1212	3/8 × 1 1/2	0.3760	1.500	0.641	0.631	7/64	0.3755	0.3735	0.4535	0.4485

All dimensions in inches.

* Key numbers indicate the nominal key dimensions. The last two digits give the nominal diameter B in eighths of an inch and the digits preceding the last two give the nominal width A in thirty-seconds of an inch. Thus, 406 indicates a key 4/32 by 6/8, or 1/8 by 3/4 in.

Key-slot Cutters. Two series of key-slot cutters, fine and coarse teeth, are standard. Both have a shank diameter of 1/2 in. for all sizes. They are designated by the key numbers used to specify the size of the key.

Table 16. Dimensions of Pratt and Whitney Keys



Key No.	L*	W	H	D	Key No.	L*	W	H	D
1	1/2	1/16	3/32	1/16	22	1 3/8	1/4	3/8	1/4
2	1/2	3/32	9/64	3/32	23	1 3/8	5/16	15/32	5/16
3	1/2	1/8	3/16	1/8	F	1 3/8	3/8	9/16	3/8
4	5/8	3/32	9/64	3/32	24	1 1/2	1/4	3/8	1/4
5	5/8	1/8	3/16	1/8	25	1 1/2	5/16	15/32	5/16
6	5/8	5/32	15/64	5/32	G	1 1/2	3/8	9/16	3/8
7	3/4	1/8	3/16	1/8	51	1 3/4	1/4	3/8	1/4
8	3/4	5/32	15/64	5/32	52	1 3/4	5/16	15/32	5/16
9	3/4	3/16	9/32	3/16	53	1 3/4	3/8	9/16	3/8
10	7/8	5/32	15/64	5/32	26	2	3/16	9/32	3/16
11	7/8	3/16	9/32	3/16	27	2	1/4	3/8	1/4
12	7/8	7/32	21/64	7/32	28	2	5/16	15/32	5/16
A	7/8	1/4	3/8	1/4	29	2	3/8	9/16	3/8
13	1	3/16	9/32	3/16	54	2 1/4	1/4	3/8	1/4
14	1	7/32	21/64	7/32	55	2 1/4	5/16	15/16	5/16
15	1	1/4	3/8	1/4	56	2 1/4	3/8	9/16	3/8
B	1	5/16	15/32	5/16	57	2 1/4	7/16	21/32	7/16
16	1 1/8	3/16	9/32	3/16	58	2 1/2	5/16	15/32	5/16
17	1 1/8	7/32	21/64	7/32	59	2 1/2	3/8	9/16	3/8
18	1 1/8	1/4	3/8	1/4	60	2 1/2	7/16	21/32	7/16
C	1 1/8	5/16	15/32	5/16	61	2 1/2	1/2	3/4	1/2
19	1 1/4	3/16	9/32	3/16	30	3	3/8	9/16	3/8
20	1 1/4	7/32	21/64	7/32	31	3	7/16	21/32	7/16
21	1 1/4	1/4	3/8	1/4	32	3	1/2	3/4	1/2
D	1 1/4	5/16	15/32	5/16	33	3	9/16	27/32	9/16
E	1 1/4	3/8	9/16	3/8	34	3	5/8	15/16	5/8

All dimensions in inches.

Key is two-thirds in shaft; one-third in hub.

Keys are 0.001 inch oversize in width to ensure proper fitting in keyway.

Keyway size: width $= W$; depth $= H - D$.

* Length L may vary but should never be less than $2W$.

Table 17. Wire and Sheet-metal Gages

Number of gage	American or Brown and Sharpe[a]	Washburn & Moen or American Steel and Wire Co.[b]	Music wire[c]	Imperial wire gage[d]	U.S. Std. for plate[e]
0000000	......	0.4900	.....	0.5000	0.5000
000000	0.5800	0.4615	0.004	0.4640	0.4688
00000	0.5165	0.4305	0.005	0.4320	0.4375
0000	0.4600	0.3938	0.006	0.4000	0.4063
000	0.4096	0.3625	0.007	0.3720	0.3750
00	0.3648	0.3310	0.008	0.3480	0.3438
0	0.3249	0.3065	0.009	0.3240	0.3125
1	0.2893	0.2830	0.010	0.3000	0.2813
2	0.2576	0.2625	0.011	0.2760	0.2656
3	0.2294	0.2437	0.012	0.2520	0.2500
4	0.2043	0.2253	0.013	0.2320	0.2344
5	0.1819	0.2070	0.014	0.2120	0.2188
6	0.1620	0.1920	0.016	0.1920	0.2031
7	0.1443	0.1770	0.018	0.1760	0.1875
8	0.1285	0.1620	0.020	0.1600	0.1719
9	0.1144	0.1483	0.022	0.1440	0.1563
10	0.1019	0.1350	0.024	0.1280	0.1406
11	0.0907	0.1205	0.026	0.1160	0.1250
12	0.0808	0.1055	0.029	0.1040	0.1094
13	0.0720	0.0915	0.031	0.0920	0.0938
14	0.0641	0.0800	0.033	0.0800	0.0781
15	0.0571	0.0720	0.035	0.0720	0.0703
16	0.0508	0.0625	0.037	0.0640	0.0625
17	0.0453	0.0540	0.039	0.0560	0.0563
18	0.0403	0.0475	0.041	0.0480	0.0500
19	0.0359	0.0410	0.043	0.0400	0.0438
20	0.0320	0.0348	0.045	0.0360	0.0375
21	0.0285	0.0317	0.047	0.0320	0.0344
22	0.0253	0.0286	0.049	0.0280	0.0313
23	0.0226	0.0258	0.051	0.0240	0.0281
24	0.0201	0.0230	0.055	0.0220	0.0250
25	0.0179	0.0204	0.059	0.0200	0.0219
26	0.0159	0.0181	0.063	0.0180	0.0188
27	0.0142	0.0173	0.067	0.0164	0.0172
28	0.0126	0.0162	0.071	0.0148	0.0156
29	0.0113	0.0150	0.075	0.0136	0.0141
30	0.0100	0.0140	0.080	0.0124	0.0125
	0.0089	0.0132	0.085	0.0116	0.0109
31			0.090	0.0108	0.0102
32	0.0080	0.0128			
33	0.0071	0.0118	0.095	0.0100	0.0094
34	0.0063	0.0104	0.100	0.0092	0.0086
35	0.0056	0.0095	0.106	0.0084	0.0078
36	0.0050	0.0090	0.112	0.0076	0.0070
37	0.0045	0.0085	0.118	0.0068	0.0066
38	0.0040	0.0080	0.124	0.0060	0.0063
39	0.0035	0.0075	0.130	0.0052	
40	0.0031	0.0070	0.138	0.0048	

All dimensions in decimal parts of an inch.

[a] Recognized standard in the United States for wire and sheet metal of copper and other metals except steel and iron.

[b] Recognized standard for steel and iron wire. Called the "U.S. steel wire gage."

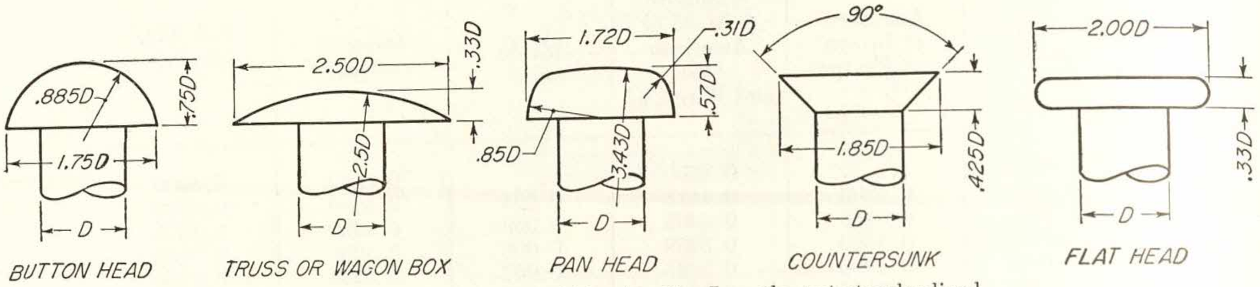
[c] American Steel & Wire Company's music or piano wire gage. Recommended by U.S. Bureau of Standards.

[d] Official British Standard.

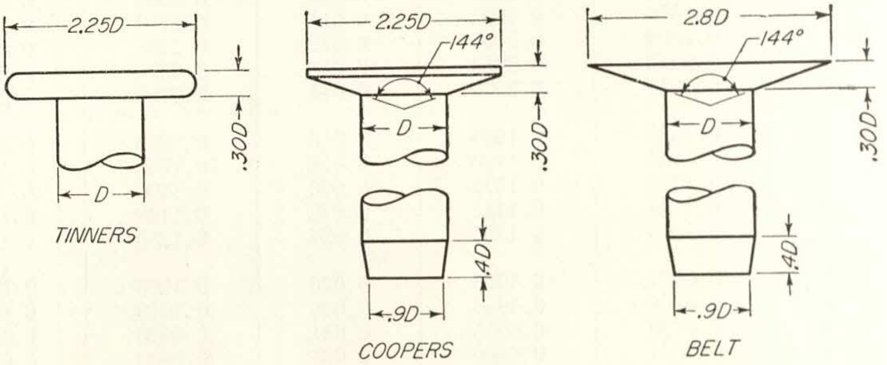
[e] Legalized U.S. Standard for iron and steel plate, although plate is now always specified by its thickness in decimals of an inch.

Preferred thicknesses for uncoated thin flat metals (under 0.250 in.), ASA B32—1941, gives recommended sizes for sheets.

Table 18. Approximate Proportions for Drawing American Standard Small Rivets*



Diameters, $\frac{3}{32}$, $\frac{1}{8}$, $\frac{5}{32}$, $\frac{3}{16}$, $\frac{7}{32}$, $\frac{1}{4}$, $\frac{9}{32}$, $\frac{5}{16}$, $\frac{11}{32}$, $\frac{3}{8}$, $\frac{7}{16}$. Lengths not standardized.



Tinner's			Cooper's			Belt		
Size No.†	Body diam.	Length	Size No.†	Body diam.	Length	Size No.‡	Body diam.	Length
8 oz	0.089	0.16	1 lb	0.109	0.219	7	0.180	From $\frac{3}{8}''$ to $\frac{3}{4}''$ by $\frac{1}{8}''$ increments
12	0.105	0.19	1½	0.127	0.256	8	0.165	
1 lb	0.111	0.20	2	0.141	0.292	9	0.148	
1½	0.130	0.23	2½	0.148	0.325	10	0.134	
2	0.144	0.27	3	0.156	0.358	11	0.120	
2½	0.148	0.28	4	0.165	0.392	12	0.109	
3	0.160	0.31	6	0.203	0.466	13	0.095	
4	0.176	0.34	8	0.238	0.571			
6	0.203	0.39	10	0.250	0.606			
8	0.224	0.44	12	0.259	0.608			
10	0.238	0.47	14	0.271	0.643			
12	0.259	0.50	16	0.281	0.677			
14	0.284	0.52						
16	0.300	0.53						

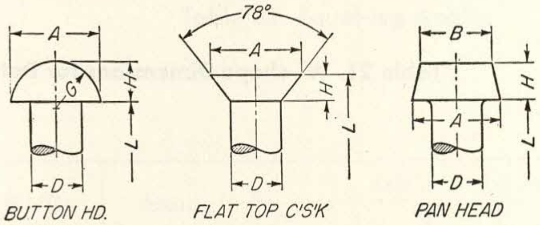
Dimensions in inches.

* From American Institute of Bolt, Nut, and Rivet Manufacturers. (1944)

† Size numbers refer to weight of 1,000 rivets.

‡ Size number refers to the Stubs iron wire gage number of the stock used in the body of the rivet.

Table 19. Approximate Proportions for Selected American Standard Large Rivets*



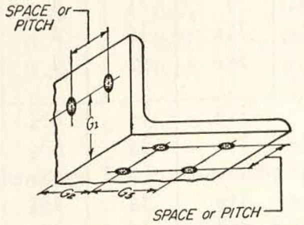
Diameter *D*	Button head			Countersunk head		Pan head		
	A	*H*	*G*	*A*	*H*	*A*	*B*	*H*
½	0.875	0.375	0.443	0.905	0.250	0.875	0.500	0.350
⅝	1.094	0.469	0.553	1.131	0.313	1.094	0.625	0.438
¾	1.313	0.563	0.664	1.358	0.375	1.313	0.750	0.525
⅞	1.531	0.656	0.775	1.584	0.438	1.531	0.875	0.613
1	1.750	0.750	0.885	1.810	0.500	1.750	1.000	0.700
1⅛	1.969	0.844	0.996	2.036	0.563	1.969	1.125	0.788
1¼	2.189	0.938	1.107	2.263	0.625	2.189	1.250	0.875
1⅜	2.406	1.031	1.217	2.489	0.688	2.406	1.375	0.963
1½	2.625	1.125	1.328	2.715	0.750	2.625	1.500	1.050
1⅝	2.844	1.219	1.439	2.941	0.813	2.844	1.625	1.138
1¾	3.063	1.313	1.549	3.168	0.875	3.063	1.750	1.225

All dimensions in inches (these are basic sizes).

* American Standard B18.4—1937.

Fillets under heads not more than 1⁄16 in. radius. Large rivet lengths range from ½ to 8 in.

Table 20. Gage and Maximum Rivet Size for Angles*



Length of leg	Max rivet size	G_1	G_2	G_3
1¾	½	1		
2	⅝	1⅛		
2½	¾	1⅜		
3	⅞	1¾		
3½	⅞	2		
4	⅞	2½		
5	1	3	2	1¾
6	1	3½	2¼	2½
7	1⅛	4	2½	3
8	1⅛	4½	3	3

Dimensions in inches.

* For spacing (or pitch) and other information see "Riveting and Riveted Joints" in Machinery's Handbook and catalogue of American Institute of Bolt, Nut, and Rivet Manufacturers.

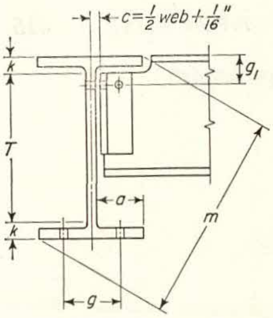
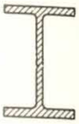


Table 21. WF-shape Dimensions for Detailing*



Nominal size	Wt./ft, lb	Depth	Flange		Web		Distance						Usual gage g
			Width	Thickness	Thickness	Half thickness	a	T	k	m	g_1	c	
36 x 16 1/2	300	36 3/4	16 5/8	1 11/16	15/16	1/2	7 7/8	31 1/8	2 13/16	40 3/8	4	9/16	5 1/2
	280	36 1/2	16 5/8	1 9/16	7/8	7/16	7 7/8	31 1/8	2 11/16	40 1/8	4	1/2	5 1/2
30 x 10 1/2	132	30 1/4	10 1/2	1	5/8	5/16	5	26 7/8	1 11/16	32 1/8	3	3/8	5 1/2
	124	30 1/8	10 1/2	15/16	5/8	5/16	5	26 7/8	1 5/8	31 7/8	3	3/8	5 1/2
	116	30	10 1/2	7/8	9/16	5/16	5	26 7/8	1 9/16	31 3/4	2 3/4	3/8	5 1/2
	108	29 7/8	10 1/2	3/4	9/16	5/16	5	26 7/8	1 1/2	31 5/8	2 3/4	3/8	5 1/2
24 x 9	94	24 1/4	9	7/8	1/2	1/4	4 1/4	21 3/8	1 7/16	25 7/8	2 3/4	5/16	5 1/2
	84	24 1/8	9	3/4	1/2	1/4	4 1/4	21 3/8	1 3/8	25 3/4	2 3/4	5/16	5 1/2
	76	23 7/8	9	11/16	7/16	1/4	4 1/4	21 3/8	1 1/4	25 5/8	2 1/2	5/16	5 1/2
16 x 11 1/2	96	16 3/8	11 1/2	7/8	9/16	5/16	5 1/2	13 1/8	1 5/8	20	2 3/4	3/8	5 1/2
	88	16 1/8	11 1/2	13/16	1/2	1/4	5 1/2	13 1/8	1 1/2	19 7/8	2 3/4	5/16	5 1/2
16 x 8 1/2	78	16 3/8	8 5/8	7/8	9/16	1/4	4	13 3/8	1 1/2	18 1/2	2 3/4	5/16	5 1/2
	71	16 1/8	8 1/2	13/16	1/2	1/4	4	13 3/8	1 3/8	18 1/4	2 3/4	5/16	5 1/2
	64	16	8 1/2	11/16	7/16	1/4	4	13 3/8	1 5/16	18 1/8	2 1/2	5/16	5 1/2
	58	15 7/8	8 1/2	5/8	7/16	1/4	4	13 3/8	1 1/4	18	2 1/2	5/16	5 1/2
14 x 12	84	14 1/8	12	3/4	7/16	1/4	5 3/4	11 3/8	1 3/8	18 5/8	2 3/4	5/16	5 1/2
	78	14	12	11/16	7/16	1/4	5 3/4	11 3/8	1 5/16	18 1/2	2 1/2	5/16	5 1/2
14 x 10	74	14 1/4	10 1/8	13/16	7/16	1/4	4 3/4	11 3/8	1 3/8	17 1/2	2 3/4	5/16	5 1/2
	68	14	10	11/16	7/16	1/4	4 3/4	11 3/8	1 5/16	17 1/4	2 1/2	5/16	5 1/2
	61	13 7/8	10	5/8	3/8	3/16	4 3/4	11 3/8	1 1/4	17 1/8	2 1/2	1/4	5 1/2
14 x 8	53	14	8	11/16	3/8	3/16	3 7/8	11 3/8	1 1/4	16 1/8	2 1/2	1/4	5 1/2
	48	13 3/4	8	9/16	3/8	3/16	3 7/8	11 3/8	1 3/16	16	2 1/2	1/4	5 1/2
	43	13 5/8	8	1/2	5/16	3/16	3 7/8	11 3/8	1 1/8	15 7/8	2 1/2	1/4	5 1/2
14 x 6 3/4	38	14 1/8	6 3/4	1/2	5/16	3/16	3 1/4	12 1/8	1	15 3/4	2 1/4	1/4	3 1/2
	34	14	6 3/4	7/16	5/16	3/16	3 1/4	12 1/8	15/16	15 5/8	2 1/4	1/4	3 1/2
	30	13 7/8	6 3/4	3/8	5/16	1/8	3 1/4	12 1/8	7/8	15 1/2	2 1/4	3/16	3 1/2
12 x 10	58	12 1/4	10	5/8	3/8	3/16	4 7/8	9 3/4	1 1/4	15 7/8	2 1/2	1/4	5 1/2
	53	12	10	9/16	3/8	3/16	4 7/8	9 3/4	1 3/16	15 5/8	2 1/2	1/4	5 1/2
12 x 8	50	12 1/4	8 1/8	5/8	3/8	3/16	3 7/8	9 3/4	1 1/4	14 5/8	2 1/2	1/4	5 1/2
	45	12	8	9/16	3/8	3/16	3 7/8	9 3/4	1 3/16	14 1/2	2 1/2	1/4	5 1/2
	40	12	8	1/2	5/16	3/16	3 7/8	9 3/4	1 1/8	14 3/8	2 1/2	1/4	5 1/2
12 x 6 1/2	36	12 1/4	6 5/8	9/16	5/16	3/16	3 1/8	10 3/8	15/16	14	2 1/4	1/4	3 1/2
	31	12 1/8	6 1/2	7/16	1/4	1/8	3 1/8	10 3/8	7/8	13 3/4	2 1/4	3/16	3 1/2
	27	12	6 1/2	3/8	1/4	1/8	3 1/8	10 3/8	13/16	13 5/8	2 1/4	3/16	3 1/2

All dimensions in inches. Gage g_1 is based on $k + 1\frac{1}{4}$ in., to nearest 1/4 in.

* AISC, "Steel Construction Manual."

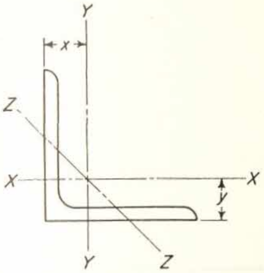
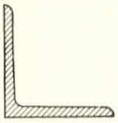
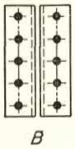


Table 22. Equal-leg Angles

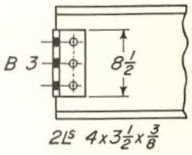
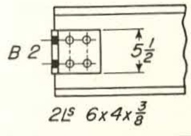


Size, in.	Thickness, in.	Wt/ft, lb	Area, sq in.	Axis X-X and Axis Y-Y				Axis Z-Z
				I, in.[4]	S, cu in.	r, in.	x or y, in.	r, in.
6 x 6	1	37.4	11.00	35.5	8.6	1.80	1.86	1.17
	⅞	33.1	9.73	31.9	7.6	1.81	1.82	1.17
	¾	28.7	8.44	28.2	6.7	1.83	1.78	1.17
	⅝	24.2	7.11	24.2	5.7	1.84	1.73	1.18
4 x 4	¾	18.5	5.44	7.7	2.8	1.19	1.27	0.78
	⅝	15.7	4.61	6.7	2.4	1.20	1.23	0.78
3 x 3	½	9.4	2.75	2.2	1.1	0.90	0.93	0.58
	7⁄16	8.3	2.43	2.0	0.95	0.91	0.91	0.58
	⅜	7.2	2.11	1.8	0.83	0.91	0.89	0.58
	5⁄16	6.1	1.78	1.5	0.71	0.92	0.87	0.59
	¼	4.9	1.44	1.2	0.58	0.93	0.84	0.59
	3⁄16	3.71	1.09	0.96	0.44	0.94	0.82	0.59
2½ x 2½	½	7.7	2.25	1.2	0.72	0.74	0.81	0.49
	⅜	5.9	1.73	0.98	0.57	0.75	0.76	0.49
	5⁄16	5.0	1.47	0.85	0.48	0.76	0.74	0.49
	¼	4.1	1.19	0.70	0.39	0.77	0.72	0.49
	3⁄16	3.07	0.90	0.55	0.30	0.78	0.69	0.49
2 x 2	⅜	4.7	1.36	0.48	0.35	0.59	0.64	0.39
	5⁄16	3.92	1.15	0.42	0.30	0.60	0.61	0.39
	¼	3.19	0.94	0.35	0.25	0.61	0.59	0.39
	3⁄16	2.44	0.71	0.27	0.19	0.62	0.57	0.39
	⅛	1.65	0.48	0.19	0.13	0.63	0.55	0.40

Table 23. Standard Beam Connections, B Series



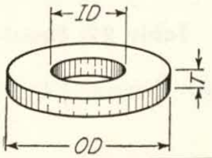
ALLOWABLE LOADS IN KIPS

	Rivets in outstanding legs		Rivets in web legs		Maximum value			
	No.	Shear	Bearing	Shear	Section	R	Section	R
	6	39.8	90t	39.8	14 WF 38 34 30 12 WF 36 31 27	28.2 25.8 24.3 27.5 23.8 21.6	12 I 50 and 40.8 35 31.8	39.8 38.5 31.5
	4	26.5	120t	53.0	10 WF (all wts.) 8 WF 20 17	26.5 26.2 23.9	10 I 35 and 25.4 8 I 23.0 and 18.4	26.5 26.5

Holes, 13⁄16 in.; rivets, ¾ in.

NOTE: A 75-page bulletin, "Hot Rolled Carbon Steel Structural Shapes," USS ADV-17831, may be obtained from United States Steel, Pittsburgh, Pa.

Table 24. American Standard Plain Washers*

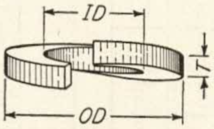


Size	Light			Medium			Heavy			Extra heavy		
	ID	OD	Thickness	ID	OD	Thickness	ID	OD	Thickness	ID	OD	Thickness
0	5/64	3/16	0.020									
1	3/32	7/32	0.020									
2	3/32	1/4	0.020									
3	1/8	1/4	0.022									
4	1/8	1/4	0.022	1/8	5/16	0.032						
5	5/32	5/16	0.035	5/32	3/8	0.049						
6	5/32	5/16	0.035	5/32	3/8	0.049						
7	11/64	13/32	0.049	3/16	3/8	0.049						
8	3/16	3/8	0.049	3/16	7/16	0.049						
9	13/64	15/32	0.049	7/32	1/2	0.049						
3/16	7/32	7/16	0.049	7/32	1/2	0.049	1/4	9/16	0.049			
10	7/32	7/16	0.049	1/4	9/16	0.049	1/4	9/16	0.065			
11	15/64	17/32	0.049	1/4	9/16	0.049	1/4	9/16	0.065			
12	1/4	1/2	0.049	1/4	9/16	0.049	1/4	9/16	0.065			
14	17/64	5/8	0.049	5/16	3/4	0.065	5/16	7/8	0.065			
1/4	9/32	5/8	0.065	5/16	3/4	0.065	5/16	3/4	0.065	5/16	7/8	0.065
16	9/32	5/8	0.065	5/16	3/4	0.065	5/16	7/8	0.065	5/16	7/8	0.065
18	5/16	3/4	0.065	3/8	3/4	0.065	3/8	7/8	0.083	3/8	1 1/8	0.065
5/16	11/32	11/16	0.065	3/8	3/4	0.065	3/8	7/8	0.083	3/8	1 1/8	0.065
20	11/32	11/16	0.065	3/8	3/4	0.065	3/8	7/8	0.083	3/8	1 1/8	0.065
24	13/32	13/16	0.065	7/16	7/8	0.083	7/16	1	0.083	7/16	1 3/8	0.083
3/8	13/32	13/16	0.065	7/16	7/8	0.083	7/16	1	0.083	7/16	1 3/8	0.083
7/16	15/32	59/64	0.065	1/2	1 1/8	0.083	1/2	1 1/4	0.083	1/2	1 5/8	0.083
1/2	17/32	1 1/16	0.095	9/16	1 1/4	0.109	9/16	1 3/8	0.109	9/16	1 7/8	0.109
9/16	19/32	1 3/16	0.095	5/8	1 3/8	0.109	5/8	1 1/2	0.109	5/8	2 1/8	0.134
5/8	21/32	1 5/16	0.095	11/16	1 1/2	0.134	11/16	1 3/4	0.134	11/16	2 3/8	0.165
3/4	13/16	1 1/2	0.134	13/16	1 3/4	0.148	13/16	2	0.148	13/16	2 7/8	0.165
7/8	15/16	1 3/4	0.134	15/16	2	0.165	15/16	2 1/4	0.165	15/16	3 3/8	0.180
1	1 1/16	2	0.134	1 1/16	2 1/4	0.165	1 1/16	2 1/2	0.165	1 1/16	3 7/8	0.238
1 1/8	.....	.....	.....	1 3/16	2 1/2	0.165	1 1/4	2 3/4	0.165			
1 1/4	.....	.....	.....	1 5/16	2 3/4	0.165	1 3/8	3	0.165			
1 3/8	.....	.....	.....	1 7/16	3	0.180	1 1/4	3 1/4	0.180			
1 1/2	.....	.....	.....	1 9/16	3 1/4	0.180	1 5/8	3 1/2	0.180			
1 5/8	.....	.....	.....	1 11/16	3 1/2	0.180	1 3/4	3 3/4	0.180			
1 3/4	.....	.....	.....	1 13/16	3 3/4	0.180	1 7/8	4	0.180			
1 7/8	.....	.....	.....	1 15/16	4	0.180	2	4 1/4	0.180			
2	.....	.....	.....	2 1/16	4 1/4	0.180	2 1/8	4 1/2	0.180			
2 1/4	.....	.....	.....	.....	.....	.....	2 3/8	4 3/4	0.220			
2 1/2	.....	.....	.....	.....	.....	.....	2 5/8	5	0.238			
2 3/4	.....	.....	.....	.....	.....	.....	2 7/8	5 1/4	0.259			
3	.....	.....	.....	.....	.....	.....	3 1/8	5 1/2	0.284			

All dimensions in inches.

* ASA B27.2—1949.

Table 25. American Standard Lock Washers*



Nominal size	Inside diam., min	Light		Medium		Heavy		Extra heavy	
		Min thickness	Outside diam, max	Min thickness	Outside diam, max	Min thickness	Outside diam, max	Min thickness	Outside diam, max
2 (0.086)	0.088	0.015	0.165	0.020	0.175	0.025	0.185	0.027	0.211
3 (0.099)	0.102	0.020	0.188	0.025	0.198	0.031	0.212	0.034	0.242
4 (0.112)	0.115	0.020	0.202	0.025	0.212	0.031	0.226	0.034	0.256
5 (0.125)	0.128	0.025	0.225	0.031	0.239	0.040	0.255	0.045	0.303
6 (0.138)	0.141	0.025	0.239	0.031	0.253	0.040	0.269	0.045	0.317
8 (0.164)	0.168	0.031	0.280	0.040	0.296	0.047	0.310	0.057	0.378
10 (0.190)	0.194	0.040	0.323	0.047	0.337	0.056	0.353	0.068	0.437
12 (0.216)	0.221	0.047	0.364	0.056	0.380	0.063	0.394	0.080	0.500
¼	0.255	0.047	0.489	0.062	0.493	0.077	0.495	0.084	0.539
5⁄16	0.319	0.056	0.575	0.078	0.591	0.097	0.601	0.108	0.627
⅜	0.382	0.070	0.678	0.094	0.688	0.115	0.696	0.123	0.746
7⁄16	0.446	0.085	0.780	0.109	0.784	0.133	0.792	0.143	0.844
½	0.509	0.099	0.877	0.125	0.879	0.151	0.889	0.162	0.945
9⁄16	0.573	0.113	0.975	0.141	0.979	0.170	0.989	0.182	1.049
⅝	0.636	0.126	1.082	0.156	1.086	0.189	1.100	0.202	1.164
11⁄16	0.700	0.138	1.178	0.172	1.184	0.207	1.200	0.221	1.266
¾	0.763	0.153	1.277	0.188	1.279	0.226	1.299	0.241	1.369
13⁄16	0.827	0.168	1.375	0.203	1.377	0.246	1.401	0.261	1.473
⅞	0.890	0.179	1.470	0.219	1.474	0.266	1.504	0.285	1.586
15⁄16	0.954	0.191	1.562	0.234	1.570	0.284	1.604	0.308	1.698
1	1.017	0.202	1.656	0.250	1.672	0.306	1.716	0.330	1.810
1 1⁄16	1.081	0.213	1.746	0.266	1.768	0.326	1.820	0.352	1.922
1 ⅛	1.144	0.224	1.837	0.281	1.865	0.345	1.921	0.375	2.031
1 3⁄16	1.208	0.234	1.923	0.297	1.963	0.364	2.021	0.396	2.137
1 ¼	1.271	0.244	2.012	0.312	2.058	0.384	2.126	0.417	2.244
1 5⁄16	1.335	0.254	2.098	0.328	2.156	0.403	2.226	0.438	2.350
1 ⅜	1.398	0.264	2.183	0.344	2.253	0.422	2.325	0.458	2.453
1 7⁄16	1.462	0.273	2.269	0.359	2.349	0.440	2.421	0.478	2.555
1 ½	1.525	0.282	2.352	0.375	2.446	0.458	2.518	0.496	2.654

All dimensions in inches.
ASA B27.1—1950.

Table 26. Preferred Limits and Fits for Cylindrical Parts*

Running and Sliding Fits (Letter Designation RC)

Nominal size range, in.	Class RC 1		Class RC 2		Class RC 3		Class RC 4		Class RC 5		Class RC 6		Class RC 7		Class RC 8		Class RC 9	
	Hole H5	Shaft g4	Hole H6	Shaft g5	Hole H6	Shaft f6	Hole H7	Shaft f7	Hole H7	Shaft e7	Hole H8	Shaft e8	Hole H9	Shaft d8	Hole H10	Shaft c9	Hole H11	Shaft
0.04–0.12	+0.2 0	−0.1 −0.25	+0.25 0	−0.1 −0.3	+0.25 0	−0.3 −0.55	+0.4 0	−0.3 −0.7	+0.4 0	−0.6 −1.0	+0.6 0	−0.6 −1.2	+1.0 0	−1.0 −1.6	+1.6 0	− 2.5 − 3.5	+2.5 0	− 4.0 − 5.6
0.12–0.24	+0.2 0	−0.15 −0.3	+0.3 0	−0.15 −0.35	+0.3 0	−0.4 −0.7	+0.5 0	−0.4 −0.9	+0.5 0	−0.8 −1.3	+0.7 0	−0.8 −1.5	+1.2 0	−1.2 −1.9	+1.8 0	− 2.8 − 4.0	+3.0 0	− 4.5 − 6.0
0.24–0.40	+0.25 0	−0.2 −0.35	+0.4 0	−0.2 −0.45	+0.4 0	−0.5 −0.9	+0.6 0	−0.5 −1.1	+0.6 0	−1.0 −1.6	+0.9 0	−1.0 −1.9	+1.4 0	−1.6 −2.5	+2.2 0	− 3.0 − 4.4	+3.5 0	− 5.0 − 7.2
0.40–0.71	+0.3 0	−0.25 −0.45	+0.4 0	−0.25 −0.55	+0.4 0	−0.6 −1.0	+0.7 0	−0.6 −1.3	+0.7 0	−1.2 −1.9	+1.0 0	−1.2 −2.2	+1.6 0	−2.0 −3.0	+2.8 0	− 3.5 − 5.1	+4.0 0	− 6.0 − 8.8
0.71–1.19	+0.4 0	−0.3 −0.55	+0.5 0	−0.3 −0.7	+0.5 0	−0.8 −1.3	+0.8 0	−0.8 −1.6	+0.8 0	−1.6 −2.4	+1.2 0	−1.6 −2.8	+2.0 0	−2.5 −3.7	+3.5 0	− 4.5 − 6.5	+5.0 0	− 7.0 −10.5
1.19–1.97	+0.4 0	−0.4 −0.7	+0.6 0	−0.4 −0.8	+0.6 0	−1.0 −1.6	+1.0 0	−1.0 −2.0	+1.0 0	−2.0 −3.0	+1.6 0	−2.0 −3.6	+2.5 0	−3.0 −4.6	+4.0 0	− 5.0 − 7.5	+6.0 0	− 8.0 −12.0
1.97–3.15	+0.5 0	−0.4 −0.7	+0.7 0	−0.4 −0.9	+0.7 0	−1.2 −1.9	+1.2 0	−1.2 −2.4	+1.2 0	−2.5 −3.7	+1.8 0	−2.5 −4.3	+3.0 0	−4.0 −5.8	+4.5 0	− 6.0 − 9.0	+7.0 0	− 9.0 −13.5
3.15–4.73	+0.6 0	−0.5 −0.9	+0.9 0	−0.5 −1.1	+0.9 0	−1.4 −2.3	+1.4 0	−1.4 −2.8	+1.4 0	−3.0 −4.4	+2.2 0	−3.0 −5.2	+3.5 0	−5.0 −7.2	+5.0 0	− 7.0 −10.5	+9.0 0	−10.0 −15.0

Clearance Locational Fits (Letter Designation LC)

Nominal size range, in.	Class LC 1		Class LC 2		Class LC 3		Class LC 4		Class LC 5		Class LC 6		Class LC 7		Class LC 8		Class LC 9		Class LC 10		Class LC 11	
	Hole H6	Shaft h5	Hole H7	Shaft h6	Hole H8	Shaft h7	Hole H9	Shaft h9	Hole H7	Shaft g6	Hole H8	Shaft f8	Hole H9	Shaft e9	Hole H10	Shaft d9	Hole H11	Shaft c11	Hole H12	Shaft	Hole H13	Shaft
0.04–0.12	+0.25 − 0	+ 0 −0.2	+0.4 − 0	+ 0 −0.2	+0.6 − 0	+ 0 −0.4	+1.0 − 0	+ 0 −1.0	+0.4 − 0	−0.1 −0.35	+0.6 − 0	−0.3 −0.9	+1.0 − 0	−0.6 −1.6	+1.6 − 0	−1.0 −2.0	+2.5 − 0	−2.5 −5.0	+ 4 − 0	− 4 − 8	+ 6 − 0	− 5 −11
0.12–0.24	+0.3 − 0	+ 0 −0.2	+0.5 − 0	+ 0 −0.3	+0.7 − 0	+ 0 −0.5	+1.2 − 0	+ 0 −1.2	+0.5 − 0	−0.15 −0.45	+0.7 − 0	−0.4 −1.1	+1.2 − 0	−0.8 −2.0	+1.8 − 0	−1.2 −2.4	+3.0 − 0	−2.8 −5.8	+ 5 − 0	−4.5 −9.5	+ 7 − 0	− 6 −13
0.24–0.40	+0.4 − 0	+ 0 −0.25	+0.6 − 0	+ 0 −0.4	+0.9 − 0	+ 0 −0.6	+1.4 − 0	+ 0 −1.4	+0.6 − 0	−0.2 −0.6	+0.9 − 0	−0.5 −1.4	+1.4 − 0	−1.0 −2.4	+2.2 − 0	−1.6 −3.0	+3.5 − 0	−3.0 −6.5	+ 6 − 0	− 5 − 11	+ 9 − 0	− 7 −16
0.40–0.71	+0.4 − 0	+ 0 −0.3	+0.7 − 0	+ 0 −0.4	+1.0 − 0	+ 0 −0.7	+1.6 − 0	+ 0 −1.6	+0.7 − 0	−0.25 −0.65	+1.0 − 0	−0.6 −1.6	+1.6 − 0	−1.2 −2.8	+2.8 − 0	−2.0 −3.6	+4.0 − 0	−3.5 −7.5	+ 7 − 0	− 6 − 13	+10 − 0	− 8 −18
0.71–1.19	+0.5 − 0	+ 0 −0.4	+0.8 − 0	+ 0 −0.5	+1.2 − 0	+ 0 −0.8	+2.0 − 0	+ 0 −2.0	+0.8 − 0	−0.3 −0.8	+1.2 − 0	−0.8 −2.0	+2.0 − 0	−1.6 −3.6	+3.5 − 0	−2.5 −4.5	+5.0 − 0	−4.5 −9.5	+ 8 − 0	− 7 − 15	+12 − 0	−10 −22
1.19–1.97	+0.6 − 0	+ 0 −0.4	+1.0 − 0	+ 0 −0.6	+1.6 − 0	+ 0 −1	+2.5 − 0	+ 0 −2.5	+1.0 − 0	−0.4 −1.0	+1.6 − 0	−1.0 −2.6	+2.5 − 0	−2.0 −4.5	+4.0 − 0	−3.0 −5.5	+6 − 0	− 5 − 11	+10 − 0	− 8 − 18	+16 − 0	−12 −28
1.97–3.15	+0.7 − 0	+ 0 −0.5	+1.2 − 0	+ 0 −0.7	+1.8 − 0	+ 0 −1.2	+3 − 0	+ 0 −3	+1.2 − 0	−0.4 −1.1	+1.8 − 0	−1.2 −3.0	+3.0 − 0	−2.5 −5.5	+4.5 − 0	−4.0 −7.0	+7 − 0	− 6 − 13	+12 − 0	− 10 − 22	+18 − 0	−14 −32
3.15–4.73	+0.9 − 0	+ 0 −0.6	+1.4 − 0	+ 0 −0.9	+2.2 − 0	+ 0 −1.4	+3.5 − 0	+ 0 −3.5	+1.4 − 0	−0.5 −1.4	+2.2 − 0	−1.4 −3.6	+3.5 − 0	−3.0 −6.5	+5.0 − 0	−5.0 −8.5	+9 − 0	− 7 − 16	+14 − 0	− 11 − 25	+22 − 0	−16 −38

Table 26. Preferred Limits and Fits for Cylindrical Parts*—(*Continued*)

Transition Locational Fits (Letter Designation LT) / Interference Locational Fits (Letter Designation LN)

Nominal size range, in.	Class LT 1			Class LT 2			Class LT 3			Class LT 4			Class LT 6			Class LT 7			Class LN 2			Class LN 3		
	Fit	Hole H7	Shaft j6	Fit	Hole H8	Shaft j7	Fit	Hole H7	Shaft k6	Fit	Hole H8	Shaft k7	Fit	Hole H8	Shaft m7	Fit	Hole H7	Shaft n6	Lim of interf	Hole H7	Shaft p6	Lim of interf	Hole H7	Shaft r6
0.04–0.12	−0.15 +0.5	+0.4 − 0	+0.15 −0.1	−0.3 +0.7	+0.6 − 0	+0.3 −0.1							−0.55 +0.45	+0.6 − 0	+0.55 +0.15	−0.5 +0.15	+0.4 − 0	+0.5 +0.25	0 0.65	+0.4 − 0	+0.65 +0.4	0.1 0.75	+0.4 − 0	+0.75 +0.5
0.12–0.24	−0.2 +0.6	+0.5 − 0	+0.2 −0.1	−0.4 +0.8	+0.7 − 0	+0.4 −0.1							−0.7 +0.5	+0.7 − 0	+0.7 +0.2	−0.6 +0.2	+0.5 − 0	+0.6 +0.3	0 0.8	+0.5 − 0	+0.8 +0.5	0.1 0.9	+0.5 − 0	+0.9 +0.6
0.24–0.40	−0.3 +0.7	+0.6 − 0	+0.3 −0.1	−0.4 +1.1	+0.9 − 0	+0.4 −0.2	−0.5 +0.5	+0.6 − 0	+0.5 +0.1	−0.7 +0.8	+0.9 − 0	+0.7 +0.1	−0.8 +0.7	+0.9 − 0	+0.8 +0.2	−0.8 +0.2	+0.6 − 0	+0.8 +0.4	0 1.0	+0.6 − 0	+1.0 +0.6	0.2 1.2	+0.6 − 0	+1.2 +0.8
0.40–0.71	−0.3 +0.8	+0.7 − 0	+0.3 −0.1	−0.5 +1.2	+1.0 − 0	+0.5 −0.2	−0.5 +0.6	+0.7 − 0	+0.5 +0.1	−0.8 +0.9	+1.0 − 0	+0.8 +0.1	−1.0 +0.7	+1.0 − 0	+1.0 +0.3	−0.9 +0.2	+0.7 − 0	+0.9 +0.5	0 1.1	+0.7 − 0	+1.1 +0.7	0.3 1.4	+0.7 − 0	+1.4 +1.0
0.71–1.19	−0.3 +1.0	+0.8 − 0	+0.3 −0.2	−0.5 +1.5	+1.2 − 0	+0.5 −0.3	−0.6 +0.7	+0.8 − 0	+0.6 +0.1	−0.9 +1.1	+1.2 − 0	+0.9 +0.1	−1.1 +0.9	+1.2 − 0	+1.1 +0.3	−1.1 +0.2	+0.8 − 0	+1.1 +0.6	0 1.3	+0.8 − 0	+1.3 +0.8	0.4 1.7	+0.8 − 0	+1.7 +1.2
1.19–1.97	−0.4 +1.2	+1.0 − 0	+0.4 −0.2	−0.6 +2.0	+1.6 − 0	+0.6 −0.4	−0.7 +0.9	+1.0 − 0	+0.7 +0.1	−1.1 +1.5	+1.6 − 0	+1.1 +0.1	−1.4 +1.2	+1.6 − 0	+1.4 +0.4	−1.3 +0.3	+1.0 − 0	+1.3 +0.7	0 1.6	+1.0 − 0	+1.6 +1.0	0.4 2.0	+1.0 − 0	+2.0 +1.4
1.97–3.15	−0.4 +1.5	+1.2 − 0	+0.4 −0.3	−0.7 +2.3	+1.8 − 0	+0.7 −0.5	−0.8 +1.1	+1.2 − 0	+0.8 +0.1	−1.3 +1.7	+1.8 − 0	+1.3 +0.1	−1.7 +1.3	+1.8 − 0	+1.7 +0.5	−1.5 +0.4	+1.2 − 0	+1.5 +0.8	0.2 2.1	+1.2 − 0	+2.1 +1.4	0.4 2.3	+1.2 − 0	+2.3 +1.6
3.15–4.73	−0.5 +1.8	+1.4 − 0	+0.5 −0.4	−0.8 +2.8	+2.2 − 0	+0.8 −0.6	−1.0 +1.3	+1.4 − 0	+1.0 +0.1	−1.5 +2.1	+2.2 − 0	+1.5 +0.1	−1.9 +1.7	+2.2 − 0	+1.9 +0.5	−1.9 +0.4	+1.4 − 0	+1.9 +1.0	0.2 2.5	+1.4 − 0	+2.5 +1.6	0.6 2.9	+1.4 − 0	+2.9 +2.0

Force and Shrink Fits (Letter Designation FN)

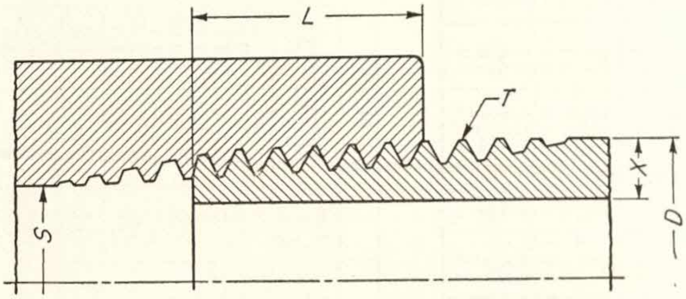
Nominal size range, in.	Class FN 1			Class FN 2			Class FN 3			Class FN 4			Class FN 5		
	Lim of interf	Hole H6	Shaft	Lim of interf	Hole H7	Shaft s6	Lim of interf	Hole H7	Shaft t6	Lim of interf	Hole H7	Shaft u6	Lim of interf	Hole H7	Shaft x7
0.04–0.12	0.05 0.5	+0.25 − 0	+0.5 +0.3	0.2 0.85	+0.4 − 0	+0.85 +0.6				0.3 0.95	+0.4 − 0	+0.95 +0.7	0.5 1.3	+0.4 − 0	+1.3 +0.9
0.12–0.24	0.1 0.6	+0.3 − 0	+0.6 +0.4	0.2 1.0	+0.5 − 0	+1.0 +0.7				0.4 1.2	+0.5 − 0	+1.2 +0.9	0.7 1.7	+0.5 − 0	+1.7 +1.2
0.24–0.40	0.1 0.75	+0.4 − 0	+0.75 +0.5	0.4 1.4	+0.6 − 0	+1.4 +1.0				0.6 1.6	+0.6 − 0	+1.6 +1.2	0.8 2.0	+0.6 − 0	+2.0 +1.4
0.40–0.56	0.1 0.8	+0.4 − 0	+0.8 +0.5	0.5 1.6	+0.7 − 0	+1.6 +1.2				0.7 1.8	+0.7 − 0	+1.8 +1.4	0.9 2.3	+0.7 − 0	+2.3 +1.6
0.56–0.71	0.2 0.9	+0.4 − 0	+0.9 +0.6	0.5 1.6	+0.7 − 0	+1.6 +1.2				0.7 1.8	+0.7 − 0	+1.8 +1.4	1.1 2.5	+0.7 − 0	+2.5 +1.8
0.71–0.95	0.2 1.1	+0.5 − 0	+1.1 +0.7	0.6 1.9	+0.8 − 0	+1.9 +1.4				0.8 2.1	+0.8 − 0	+2.1 +1.6	1.4 3.0	+0.8 − 0	+3.0 +2.2
0.95–1.19	0.3 1.2	+0.5 − 0	+1.2 +0.8	0.6 1.9	+0.8 − 0	+1.9 +1.4	0.8 2.1	+0.8 − 0	+2.1 +1.6	1.0 2.3	+0.8 − 0	+2.3 +1.8	1.7 3.3	+0.8 − 0	+3.3 +2.5
1.19–1.58	0.3 1.3	+0.6 − 0	+1.3 +0.9	0.8 2.4	+1.0 − 0	+2.4 +1.8	1.0 2.6	+1.0 − 0	+2.6 +2.0	1.5 3.1	+1.0 − 0	+3.1 +2.5	2.0 4.0	+1.0 − 0	+4.0 +3.0
1.58–1.97	0.4 1.4	+0.6 − 0	+1.4 +1.0	0.8 2.4	+1.0 − 0	+2.4 +1.8	1.2 2.8	+1.0 − 0	+2.8 +2.2	1.8 3.4	+1.0 − 0	+3.4 +2.8	3.0 5.0	+1.0 − 0	+5.0 +4.0
1.97–2.56	0.6 1.8	+0.7 − 0	+1.8 +1.3	0.8 2.7	+1.2 − 0	+2.7 +2.0	1.3 3.2	+1.2 − 0	+3.2 +2.5	2.3 4.2	+1.2 − 0	+4.2 +3.5	3.8 6.2	+1.2 − 0	+6.2 +5.0
2.56–3.15	0.7 1.9	+0.7 − 0	+1.9 +1.4	1.0 2.9	+1.2 − 0	+2.9 +2.2	1.8 3.7	+1.2 − 0	+3.7 +3.0	2.8 4.7	+1.2 − 0	+4.7 +4.0	4.8 7.2	+1.2 − 0	+7.2 +6.0
3.15–3.94	0.9 2.4	+0.9 − 0	+2.4 +1.8	1.4 3.7	+1.4 − 0	+3.7 +2.8	2.1 4.4	+1.4 − 0	+4.4 +3.5	3.6 5.9	+1.4 − 0	+5.9 +5.0	5.6 8.4	+1.4 − 0	+8.4 +7.0

Limits are in thousandths of an inch. All figures for hole and shaft are standard limits. Limits for hole and shaft are applied algebraically (added to or subtracted from) the basic size to obtain the limits of size for the parts. Symbols (H5, g5, etc.) are hole and shaft designations used in ABC (American, British, Canadian) system.

* Extracted from ASA B4.1—1955. For larger sizes see standard.

Table 27. American Standard Pipe[a]

Welded Wrought Iron



Nominal pipe size	Actual outside diam *D*	Tap-drill size *S*	Thds per in. *T*	Distance pipe enters fittings *L*	Wall thickness *X*			Weight—pounds per foot[e]		
					Standard 40[b]	Extra strong 80[c]	Double extra strong[d]	Standard 40[b]	Extra strong 80[c]	Double extra strong[d]
$\frac{1}{8}$	0.405	$\frac{11}{32}$	27	$\frac{3}{16}$	0.070	0.098	.....	0.25	0.32	
$\frac{1}{4}$	0.540	$\frac{7}{16}$	18	$\frac{9}{32}$	0.090	0.122	.....	0.43	0.54	
$\frac{3}{8}$	0.675	$\frac{37}{64}$	18	$\frac{19}{64}$	0.093	0.129	.....	0.57	0.74	
$\frac{1}{2}$	0.840	$\frac{23}{32}$	14	$\frac{3}{8}$	0.111	0.151	0.307	0.86	1.09	1.714
$\frac{3}{4}$	1.050	$\frac{59}{64}$	14	$\frac{13}{32}$	0.115	0.157	0.318	1.14	1.48	2.440
1	1.315	$1\frac{5}{32}$	$11\frac{1}{2}$	$\frac{1}{2}$	0.136	0.183	0.369	1.68	2.18	3.659
$1\frac{1}{4}$	1.660	$1\frac{1}{2}$	$11\frac{1}{2}$	$\frac{35}{64}$	0.143	0.195	0.393	2.28	3.00	5.214
$1\frac{1}{2}$	1.900	$1\frac{47}{64}$	$11\frac{1}{2}$	$\frac{9}{16}$	0.148	0.204	0.411	2.72	3.64	6.408
2	2.375	$2\frac{7}{32}$	$11\frac{1}{2}$	$\frac{37}{64}$	0.158	0.223	0.447	3.66	5.03	9.029
$2\frac{1}{2}$	2.875	$2\frac{5}{8}$	8	$\frac{7}{8}$	0.208	0.282	0.565	5.80	7.67	13.695
3	3.5	$3\frac{1}{4}$	8	$\frac{15}{16}$	0.221	0.306	0.615	7.58	10.3	18.583
$3\frac{1}{2}$	4.0	$3\frac{3}{4}$	8	1	0.231	0.325	.....	9.11	12.5	......
4	4.5	$4\frac{1}{4}$	8	$1\frac{1}{16}$	0.242	0.344	0.690	10.8	15.0	27.451
5	5.563	$5\frac{5}{16}$	8	$1\frac{5}{32}$	0.263	0.383	0.768	14.7	20.8	38.552
6	6.625	$6\frac{5}{16}$	8	$1\frac{1}{4}$	0.286	0.441	0.884	19.0	28.6	53.160
8	8.625	.....	8	$1\frac{15}{32}$	0.329	0.510	0.895	28.6	43.4	72.424
10	10.75	.....	8	$1\frac{43}{64}$	0.372	0.606	.....	40.5	64.4	
12	12.75	.....	8	$1\frac{7}{8}$	0.414	0.702	.....	53.6	88.6	
14 OD	14.0	.....	8	2	0.437	0.750	.....	62.2	104.	
16 OD	16.0	.....	8	$2\frac{13}{64}$	0.500	.....	.....	81.2		
18 OD	18.0	.....	8	$2\frac{13}{32}$	0.562	.....	.....	103.		
20 OD	20.0	.....	8	$2\frac{19}{32}$	0.562	.....	.....	115.		
24 OD	24.0	.....	8	3						

All dimensions in inches.

A pipe size may be designated by giving the nominal pipe size and wall thickness, or by giving the nominal pipe size and weight per linear foot.

[a] For welded and seamless steel pipe see ASA B36.10—1939.

[b] Refers to American Standard schedule numbers, approximate values for the expression 1,000 × P/S. Schedule 40—standard weight.

[c] Schedule 80—extra strong.

[d] Not American Standard, but commercially available in both wrought iron and steel.

[e] Plain ends.

Table 28. American Standard Graphical Symbols*

PIPING

Piping, in general ____*(Lettered with name of material conveyed)*

Non-intersecting pipes ——|——|——|——

(To differentiate lines of piping on a drawing the following symbols may be used)

Air ——←——←——←——←——	*Cold water* ——————	*Steam* ——————
Gas - - - - - - - - - - -	*Hot water* ——-——-——	*Condensate* - - - - - - - -
Oil ——···——···——	*Vacuum* ——•——•——•——•——	*Refrigerant* ——+——+——+——

PIPE FITTINGS AND VALVES

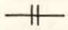
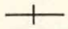
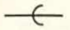
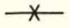
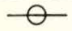
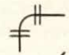
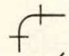
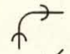
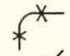
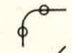
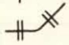
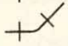
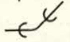
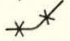
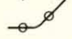
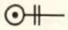
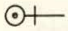
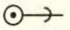
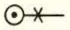
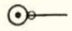
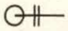
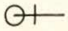
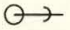
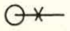
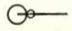
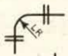
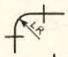
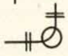
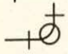
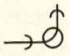
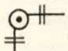
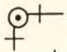
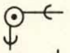
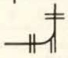
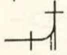
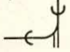
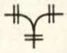
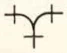
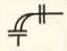
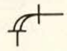
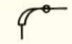
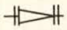
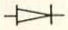
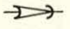
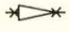
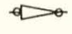
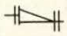
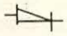
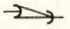
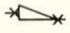
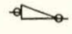
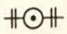
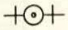
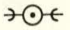
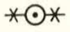
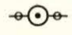
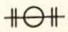
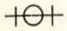
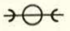
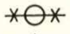
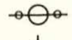
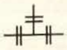
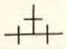
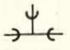
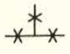
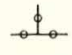
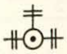
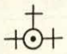
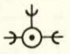
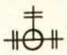
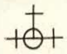
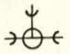
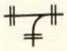
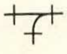
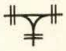
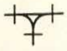
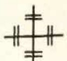
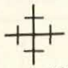
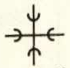
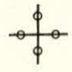
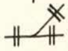
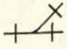
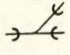
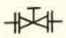
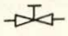
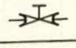
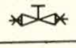
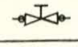
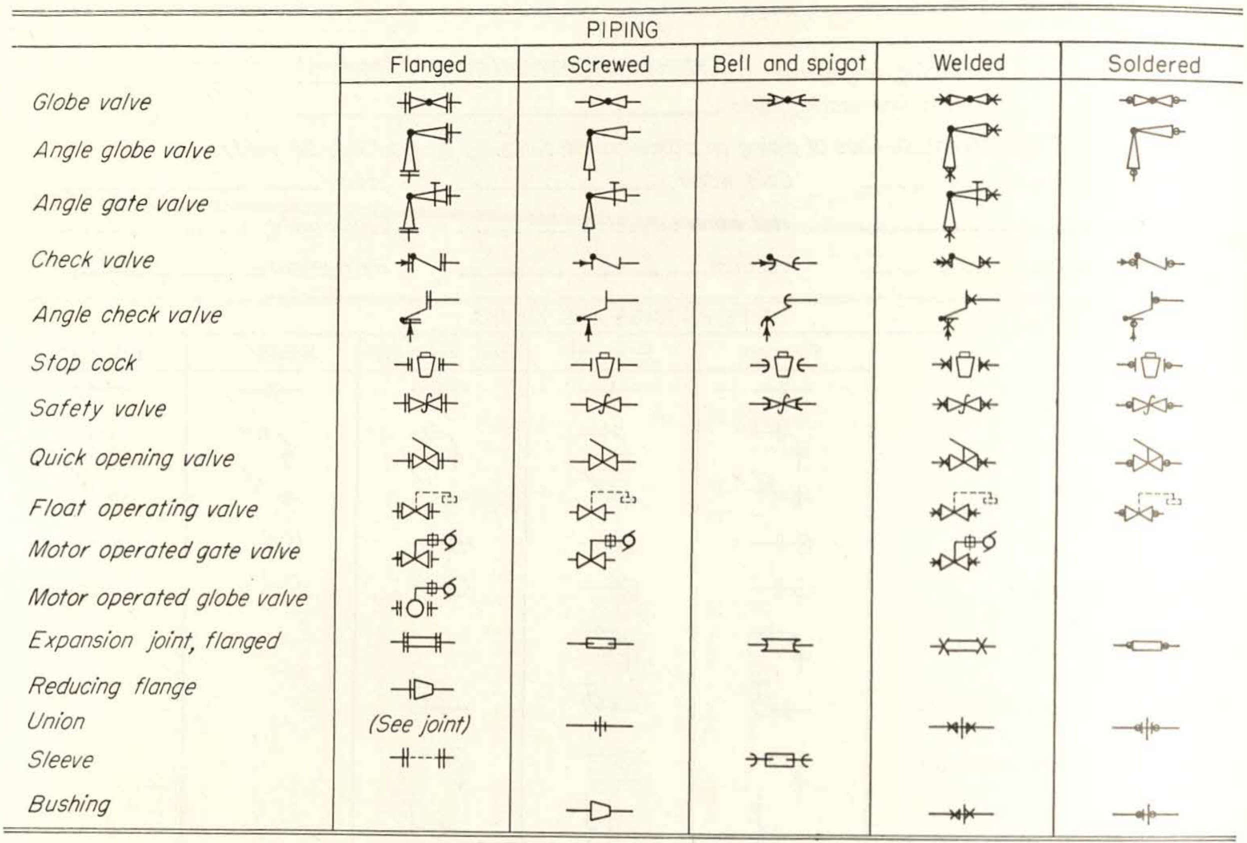
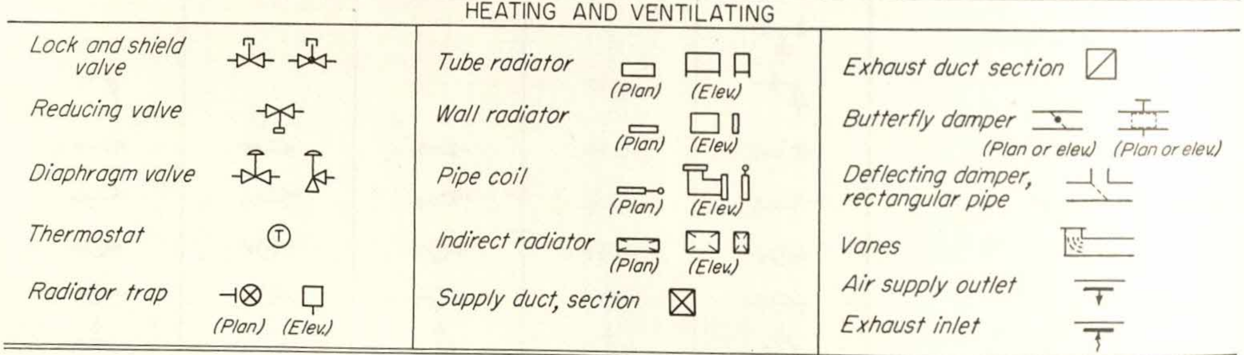
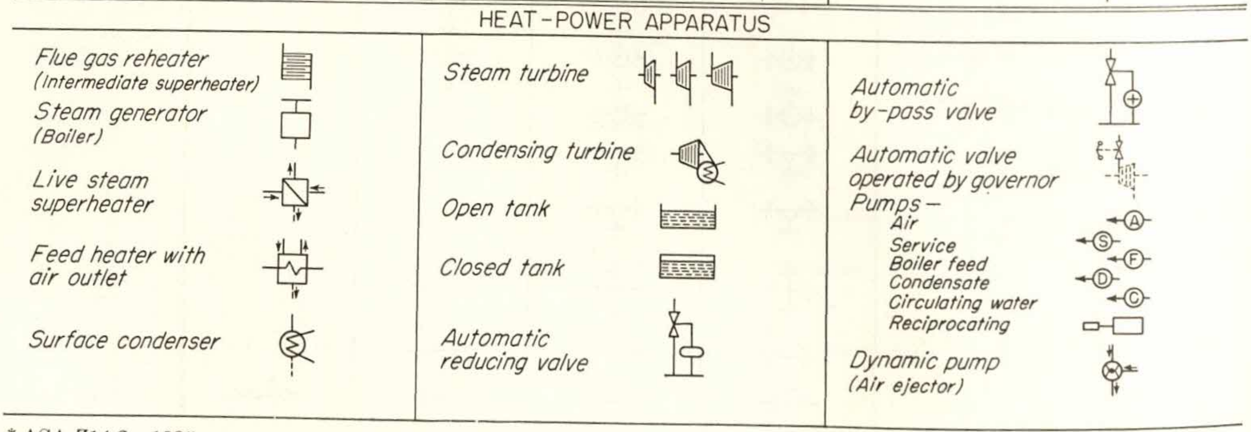
	Flanged	Screwed	Bell and spigot	Welded	Soldered
Joint					
Elbow – 90 deg.					
Elbow – 45 deg.					
Elbow – turned up					
Elbow – turned down					
Elbow – long radius					
Side outlet elbow, outlet down					
Side outlet elbow, outlet up					
Base elbow					
Double branch elbow					
Reducing elbow					
Reducer					
Eccentric reducer					
Tee – outlet up					
Tee – outlet down					
Tee					
Side outlet tee, outlet up					
Side outlet tee, outlet down					
Single sweep tee					
Double sweep tee					
Cross					
Lateral					
Gate valve					

Table 28. American Standard Graphical Symbols*— *(Continued)*







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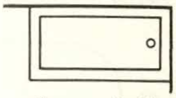
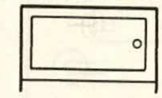
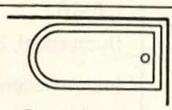
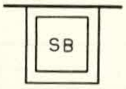
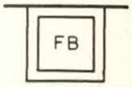
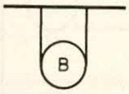
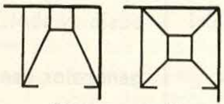
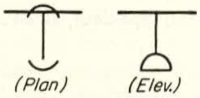
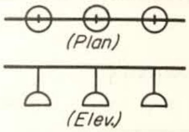
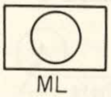
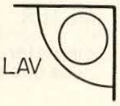
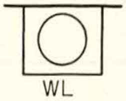
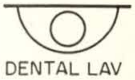
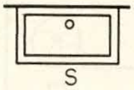
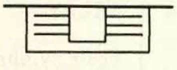
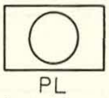
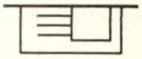
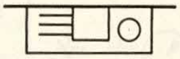
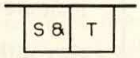
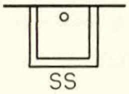
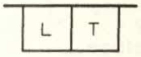
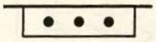
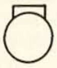
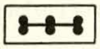
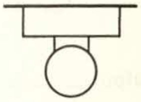
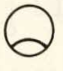
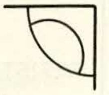
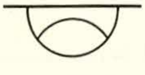
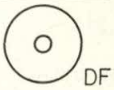
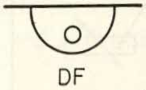
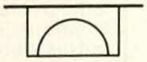
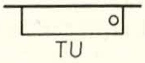
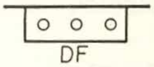
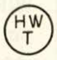
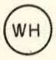
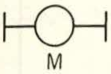
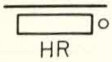
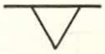
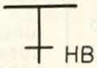
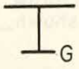
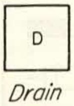
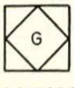
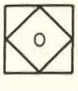
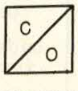
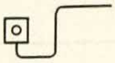
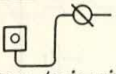
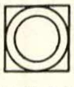
* ASA Z14.2—1935.

Table 29. American Standard Plumbing Symbols*

 Corner bath	 Recessed bath	 Roll rim bath	 Sitz bath
 Foot bath	 Bidet	 Shower stall	 Shower head
 Overhead gang shower	 Manicure lavatory Medical lavatory	 Corner lavatory	 Wall lavatory
 Dental lavatory	 Plain kitchen sink	 Kitchen sink R. & L. drain board	 Pedestal lavatory
 Kitchen sink L.H. drain board	 Combination sink and dishwasher	 Combination sink and laundry tray	 Service sink
 Laundry tray	 Wash sink (wall type)	 Water closet (no tank)	 Wash sink
 Water closet (low tank)	 Urinal (pedestal type)	 Urinal (corner type)	 Urinal (wall type)
 Drinking fountain (pedestal type)	 Drinking fountain (wall type)	 Urinal (stall type)	 Urinal (trough type)

 Drinking fountain (trough type)	 Hot water tank	 Water heater	 Meter	 Hose rack
 Vacuum outlet	 Hose bib	 Gas outlet	 Drain	 Grease separator
 Oil separator	 Cleanout	 Garage drain	 Floor drain with backwater valve	 Roof sump

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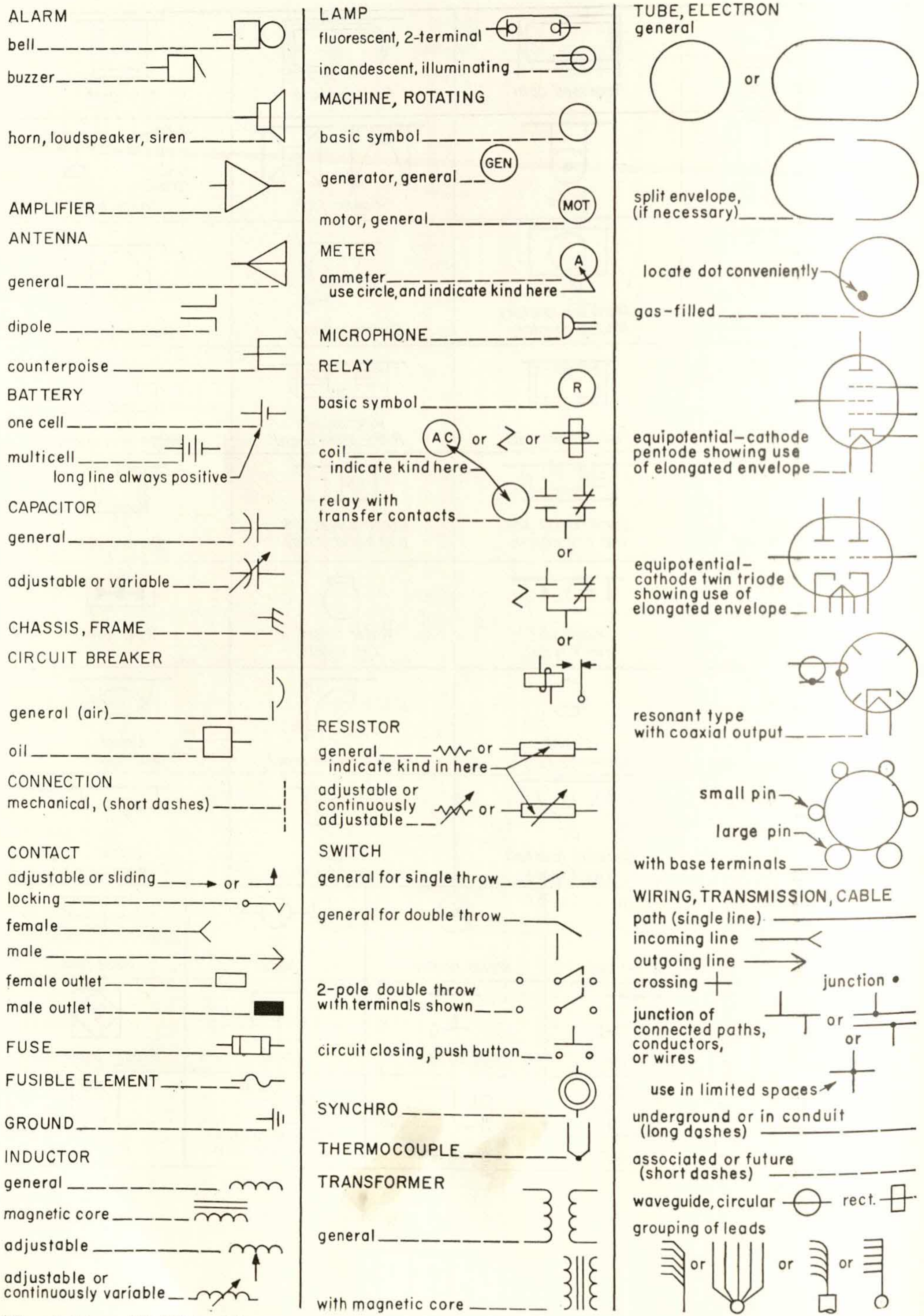
* ASA Z14.2—1935.

Table 30. American Standard Graphical Symbols for Electrical Diagrams*



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*Compiled from ASA Y32.2—1954.

Table 31. Graphical Electrical Symbols for Architectural Plans*

Ceiling	Wall	GENERAL OUTLETS
○	-○	*Outlet*
Ⓑ	-Ⓑ	*Blanked outlet*
Ⓓ		*Drop cord*
Ⓔ	-Ⓔ	*Electric outlet: for use only when circle used alone might be confused with columns, plumbing symbols, etc.*
ⓧ	-ⓧ	*Exit light outlet*
Ⓒ	-Ⓒ	*Clock outlet (specify voltage)*
		CONVENIENCE OUTLETS
	=⊖	*Duplex convenience outlet*
	=⊖$_{1,3}$	*Convenience outlet other than duplex 1=single, 3=triplex, etc.*
	=⊖-[R]	*Radio and convenience outlet*
	▲	*Special purpose outlet (des. in spec.)*
	⊙	*Floor outlet*
		SWITCH OUTLETS
	S	*Single pole switch*
	S_2	*Double pole switch*
	S_3	*Three way switch*
	S_F	*Fused switch*
	S_{WF}	*Weatherproof fused switch*
		SPECIAL OUTLETS
○$_{a,b,c,etc.}$ =⊖$_{a,b,c,etc.}$ $S_{a,b,c,etc.}$		*Any standard symbol as given above with the addition of a lower case subscript letter may be used to designate some special variation of standard equipment of particular interest in a specific set of architectural plans.* *When used they must be listed in the key of symbols on each drawing and if necessary further described in the specifications.*

	PANELS, CIRCUITS, AND MISCELLANEOUS
■	*Lighting panel*
▨	*Power panel*
——	*Branch circuit; concealed in ceiling or wall*
- - -	*Branch circuit; concealed in floor*
----	*Branch circuit; exposed*
→→	*Home run to panel board. Indicate number of circuits by number of arrows.* *Note: Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: -///- (3 wires), -////- (4 wires), etc.*
━━	*Feeders. Note: Use heavy lines and designate by number corresponding to listing in feeder schedule.*
	AUXILIARY SYSTEMS
⧏	*Telephone switchboard*
Ⓣ	*Bell-ringing transformer*
[D]	*Electric door opener*
⧗	*City fire alarm station*
[FA]	*Fire alarm central station*
[FS]	*Automatic fire alarm device*
[W]	*Watchman's station*
-----	*Auxiliary system circuits* *Note: Any line without further designation indicates a 2-wire system. For a greater number of wires designate with numerals in manner similar to ——— 12-No. 18W-3/4"C., or designate by number corresponding to listing in schedule.*
□$_{a,b,c}$	*Special auxiliary outlets* *Subscript letters refer to notes on plans or detailed description in specifications.*

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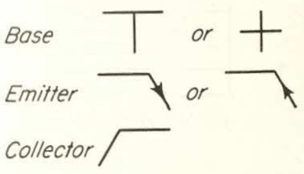
* Compiled from ASA Y32.9—1943.

Table 32. Transistor Symbols

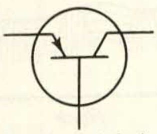
The following transistor symbols have been proposed by the Institute of Radio Engineers and will probably be adopted by the ASA:

Components:

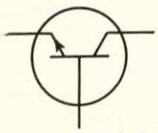


Note: Arrowhead shall be filled and shall not touch adjacent line(s). It shows the direction of current flow

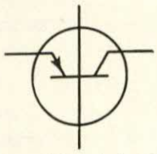
Typical Built-up Examples. The circles representing envelopes may be omitted. When drawn, they are usually made smaller than circles used for electron-tube envelopes.



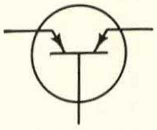
Transistor triode
N-type point contact or
PNP junction transistor



Transistor triode
P-type point contact or
NPN junction transistor



Transistor tetrode
Having base connections
on opposite sides of semi-
conductor base region



Symmetrical transistor
triode

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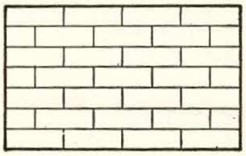
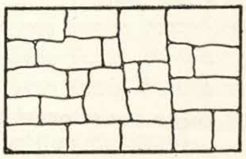
* ASA Y32.2—1954.

Table 33. Symbols for Materials

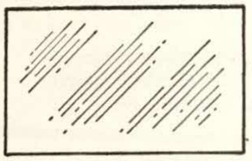
Exterior



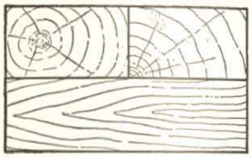
Brick



Stone

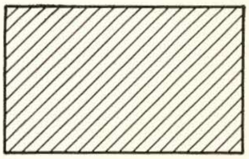


Transparent material glass, celluloid, etc.

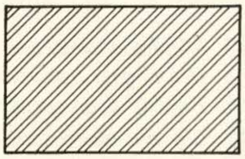


Wood

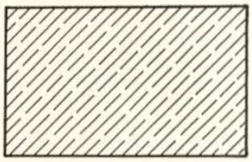
Section



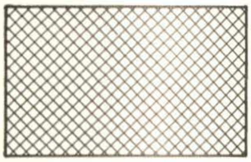
Cast iron



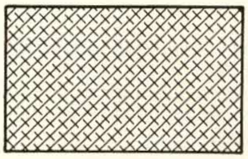
Steel



Bronze, brass, copper and composition

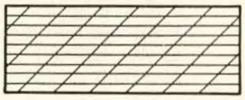


White metal, zinc, lead, babbitt & alloys

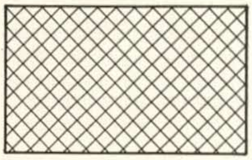


Aluminum

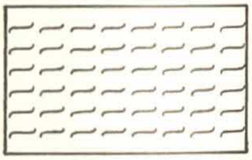
(Show solid for narrow sections)



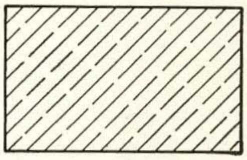
Electric insulation, mica, fibre, vulcanite, bakelite, etc.



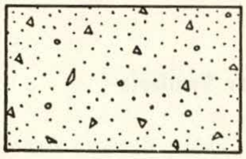
Sound or heat insulation cork, asbestos, packing, etc.



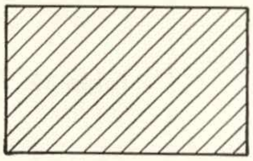
Flexible material fabric, rubber, etc.



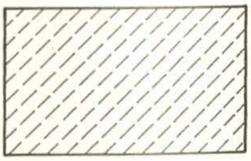
Fire brick and refractory material



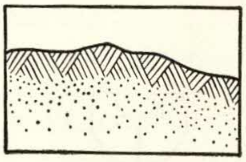
Concrete



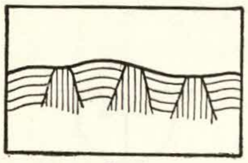
Brick or stone masonry



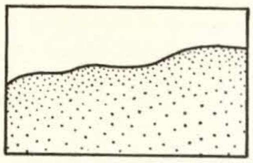
Marble, slate, glass, porcelain, etc.



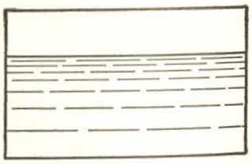
Earth



Rock



Sand



Water & other liquids

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* ASA Y32.9—1943.

American Standard Abbreviations for Use on Drawings

Addendum	ADD.
Alteration	ALTN
Aluminum	AL
American Standard	AMER STD
American Standards Association	ASA
American wire gage	AWG
Appendix	APPX
Approved	APPD
Approximate	APPROX
Arc weld	ARC/W
Area	A
Assemble	ASSEM
Assembly	ASSY
Attach	ATT
Auxiliary	AUX
Average	AVG
Babbitt	BAB
Ball bearing	BB
Bearing	BRG
Between centers	BC
Bill of material	B/M
Blueprint	BP
Bolt circle	BC
Bottom	BOT
Bracket	BRKT
Brass	BRS
Break	BRK
Brinell hardness	BH
Broach	BRO
Bronze	BRZ
Bushing	BUSH.
Cap screw	CAP SCR
Carburize	CARB
Case-harden	CH
Casting	CSTG
Cast iron	CI
Castle nut	CAS NUT
Cast steel	CS
Center	CTR
Center line	CL
Center to center	C to C
Chamfer	CHAM
Chord	CHD
Circle	CIR
Circular pitch	CP
Cold-rolled steel	CRS
Company	CO
Concentric	CONC
Copper	Cu, COP.
Correct	CORR
Counterbore	CBORE
Counterdrill	CDRILL
Countersink	CSK
Cross section	X-SECT
Decimal	DEC
Degree	(°), DEG
Department	DEPT
Design	DSGN
Detail	DET
Diagonal	DIAG
Diameter	DIA
Diametral pitch	DP
Distance	DIST
Draftsman	DFTSMN
Drawing	DWG
Drill	DR
Drive fit	DF
Drop forge	DF
Each	EA
Electric	ELEC
Engineer	ENGR
Equal	EQ
External	EXT
Extra heavy	X HVY
Fabricate	FAB
Far side	FS
Feet	(′), FT
Fillet	FIL
Fillister	FIL
Finish	FIN
Finish all over	FAO
Fitting	FTG

Flange	FLG
Flat Head	FH
Foot	('), FT
Forged steel	FST
Forging	FORG
Foundry	FDRY
Gage	GA
Galvanize	GALV
Girder	G
Grade	GR
Grind	GRD
Half round	H RD
Hard drawn	HD
Harden	HDN
Head	HD
Headless	HDLS
Heat-treat	HT TR
Heavy	HVY
Height	HGT
Hexagon	HEX
High-speed steel	HSS
Horizontal	HOR
Hot-rolled steel	HRS
Inch	("), IN.
Inside diameter	ID
Internal	INT
Intersect	INT
Iron	I
Key	K
Keyseat	KST
Keyway	KWY
Left hand	LH
Length	LG
Length over all	LOA
Light	LT
Line	L
Long	LG
Longitudinal	LONG
Machine	MACH
Machine steel	MS
Male and female	M&F
Malleable iron	MI
Manual	MAN.
Material	MATL
Maximum	MAX
Mechanical	MECH
Metal	MET.
Minimum	MIN
Minute	('), MIN
Miscellaneous	MISC
Model	MOD
National	NATL
Near side	NS
Nominal	NOM
Not to scale	NTS
Number	NO.
Obsolete	OBS
Octagon	OCT
On center	OC
Original	ORIG
Outside diameter	OD
Outside radius	OR
Over-all	OA
Parallel	PAR.
Part	PT
Pattern	PATT
Perpendicular	PERP
Piece	PC
Pitch	P
Pitch diameter	PD
Plastic	PLSTC
Point	PT
Quadrant	QUAD
Quantity	QTY
Radial	RAD
Radius	R
Ream	RM
Recommend	RECM
Rectangle	RECT
Reference	REF
Required	RQD
Revise	REV
Revolutions per minute	RPM
Right	RT
Right hand	RH
Riser	R
Rivet	RIV
Rockwell hardness	RH
Rough	RGH
Round	RD
Sand blast	SD BL
Schematic	SCHEM
Screw	SCR
Section	SECT
Semifinished	SF
Series	SER
Setscrew	SS
Shaft	SFT
Sheet	SH
Shop order	SO
Society of Automotive Engineers	SAE
Specification	SPEC
Spherical	SPHER
Spot faced	SF
Spring	SPG
Square	SQ
Stainless steel	SST
Stamp	STP
Standard	STD
Steel	STL
Steel casting	STL CSTG
Stock	STK
Straight	STR
Structural	STR
Substitute	SUB
Surface	SUR

Symbol	SYM
Symmetrical	SYM
Tangent	TAN.
Taper	TPR
Tee	T
That is	IE
Thick	THK
Thread	THD
Threads per inch	TPI
Tolerance	TOL
Tool steel	TS
Tooth	T
Typical	TYP
United States Standard	USS
Vertical	VERT
Volume	VOL
Washer	WASH.
Weight	WT
Width	W
Wire	W
Wood	WD
Woodruff	WDF
Wrought iron	WI

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